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AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS

(INCORPORATED) and Petroleum

PETROLEUM DEVELOPMENT AND TECHNOLOGY 1930

PETROLEUM DIVISION

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LETTER OF TRANSMITTAL

H. Foster Bain, Secretary,
American Institute of Mining and Metallurgical Engineers,
29 West 39th Street,
New York, N. Y.

Dear Sir:

I take pleasure in transmitting herewith Transactions, Petroleum Development and Technology, 1930, consisting of 70 papers and discussions on subjects relating to Unit Operation, Production Engineering, Petroleum Research, Refinery Engineering, Petroleum Production both at home and abroad, Petroleum Economics and Engineering Education. The several papers were presented at sessions in Los Angeles and Tulsa in October, 1929, and at the annual meeting in New York in February, 1930.

At the Tulsa Meeting it was decided to undertake a special study of unit operation with the primary object of determining, first, the extent to which fields throughout the world are now being handled as units, and second, to measure, so far as possible, the advantages of unit operation in reducing costs and increasing the extraction of oil. This study was a logical outgrowth of previous work by the Division. For several years and especially since 1926, a large amount of study by the Division has been devoted to gas-oil ratios, pressure maintenance, rejuvenation of oil fields, air-gas lift and its effect on ultimate production, well spacing, and kindred subjects, all of which have a direct bearing on the problem of unit operation, which is fundamentally an opportunity rather than an end in itself. The removal of competitive boundaries in any pool makes possible the adoption of advanced engineering practices not otherwise fully available. In this volume will be found a special chapter on well spacing. This study and that on unit operation are only well started and it is hoped that further contributions bearing on them will be developed.

With the enlarged activity of the Division during 1929, a very serious problem presented itself in selecting papers for this volume. The committee found manuscripts for approximately 800 pages whereas only 600 pages of space were available. Consequently it was mandatory that a number of papers be omitted. In general, in making selection for the volume, groups of papers bearing on a particular subject were

retained and papers which more or less stood by themselves were recommended as *Technical Publications.* All contributions presented during the year, however, appear in the table of contents and in the index of this volume. In following this procedure several papers regarded most highly by the committee are not included; in others it has been necessary to omit parts of papers. This procedure has doubtless led to injustice in some cases but the committee made a very earnest effort to reduce it to a minimum.

I desire to express personal appreciation to my fellow officers in the Petroleum Division during 1929. These men all worked diligently and capably throughout the year and contributed most largely to its success. Many engineers, not members of the Petroleum Division, have participated in our discussion and to these thanks are extended.

It is believed that in 1929 the Petroleum Division continued its progress as a forum for technical discussion of petroleum problems and the active group of officers elected for 1930 indicates that further advances will be made in establishing its usefulness to the industry.

Respectfully submitted,
J. B. UMPLEBY, *Chairman,*
Petroleum Division, 1929.

PLANS OF PETROLEUM DIVISION FOR 1930

H. Foster Bain, Secretary,
American Institute of Mining and Metallurgical Engineers,
New York, N. Y.
Dear Sir:

The Petroleum Division of the American Institute of Mining and Metallurgical Engineers plans three meetings for the year 1930–1931; the first at Los Angeles, probably the latter part of September; the second at Tulsa, Oct. 2–3, the two days preceding the International Petroleum Exposition and Congress; the third at the annual meeting in New York, in February.

The principal topics at the fall meetings will be engineering problems of unit operation, near-unit operation and proration agreements; particularly problems of recovery, economics of recovery and development, and conservation of natural resources. There will be papers presenting new developments in the technology of production engineering, such as effect of repressuring on water encroachment, natural water flood of oil sands, physical characteristics of ideal rotary muds and effect of heat and pressure on different cements, and probably one paper on the supply and demand of petroleum and its products.

The meeting in New York will again extend over three days in order to avoid concurrent sessions. The topics will be unitization, production engineering, engineering education, domestic production review, foreign production review, economics, and engineering research. Annual summaries of production engineering, production, economics and refining will be presented at an evening session.

Efforts will be made to obtain manuscripts early enough to secure the advantages of printing prior to the meeting and to eliminate mimeographing. The Committee also hopes to reduce the time required for presentation of papers by requesting authors to present abstracts, especially when an author is unable to attend the session.

The establishment of a Lucas Medal for outstanding accomplishments in Petroleum Engineering is planned. This has been under consideration for some time, and the Committee believes that arrangements can be completed before the end of the year.

Respectfully submitted,
C. V. Millikan, *Chairman*,
Petroleum Division, 1930.

Chapter I. Unit Operation

Introduction

Prompted by the general interest that is now being manifested regarding unitization the Petroleum Division at its October, 1929, meeting at Tulsa, Oklahoma, resolved:

> That the Petroleum Division of the A. I. M. E. make a special study of the advantages of unit operation and means of promoting it and that a record of existing results be assembled for general discussion at the New York Meeting in February, 1930.

To carry out the purposes of that resolution, with Earl Oliver of Ponca City as general chairman, Joseph Jensen, of Los Angeles, was named chairman of a group to report on unit operation in California; Fred E. Wood, of Casper, on the Rocky Mountain Region; A. W. Ambrose and C. E. Beecher, of Bartlesville, on Kansas and Oklahoma; Frederic H. Lahee, of Dallas, on Texas, Arkansas, Louisiana and New Mexico; and Harry H. Hill and E. L. Estabrook, of New York City, on the Appalachian Region and foreign fields. Each of these gentlemen selected as helpers many members of the Petroleum Division.

In later pages the Committee report is presented first and includes discussion at the New York and Tulsa meetings. The report and discussion are followed by three papers contributed by members of the Petroleum Division as individuals. These papers are in no sense sponsored by the Unitization Committee but it is believed that they contribute to general thought on the subject and may stimulate valuable discussion.

Committee Reports

General Summary by Unitization Committee

(New York Meeting, February, 1930)

Unitization—in some form from simple agreements among operators to complete consolidation of ownerships—is a means of obviating the wastes of unrestrained competition among owners in extracting oil and gas from a common reservoir, as well as of adjusting its output to the current needs of its owners. It offers opportunity for application of improved production methods which are expected to increase recovery, decrease developing and operating costs, and assist in stabilizing output.

Questionnaires were sent to members of the Petroleum Division. Much information was developed but a period of three months was found inadequate to complete the study. Unfortunately the papers presented at this meeting must be considered "progress reports" rather than finished work. Definite conclusions would be premature. No final recommendations are yet possible other than to state it is the opinion of the Committee that Unitization is a logical and desirable trend in the oil industry, with sufficient public interest involved to warrant the continued study by and support of the Petroleum Division.

The study thus far has discovered a definite trend toward unitization with much sympathy for it and many embryonic units already in existence, but their development in most instances has not progressed to the point where results can be tabulated to show their full significance. Neither has the movement progressed to the point where any single method of unitization has been evolved that is accepted even by its authors as the one correct method to bring about unit operation. Each attempt is admittedly imperfect and incomplete and represents an independent experimental groping toward, rather than an arrival at, the method which will serve as a standard for future efforts. This is said notwithstanding each of these attempts is much in advance of the unorganized competitive style of development, and many already show substantial economic rewards.

Experience over at least one more year should be allowed to prove or disprove contentions that we hope will be promoted at this meeting. Discussion is very much desired. Points against as well as for unit operation should be brought out. Furthermore the proper scope and character of this study should be discussed.

Information that was developed by the questionnaires was compiled into the several progress reports presented at this meeting.

Progress of Unitization in United States and Foreign Fields

Popularly the term "unitization" has been expanded to include all of the partial steps that are being taken toward the ideal of unit operation, such as drilling and spacing agreements, cooperative repressuring and flooding, etc. Approximately 185 projects that might be included within that classification were reported to the several committees. They were distributed as follows:

Singly Operated Pools	
United States Pools	15 ±
Foreign Pools	37
Total	52 ±

Some Degree of Unitization	
California Pools	15
Oklahoma-Kansas	57
Texas-Lousiana, etc	30 ±
Rocky Mountain	27
Foreign	4
Total	133 ±

World production during 1928 totaled 1,322,370,000 bbl. Of this amount the United States produced 901,474,000 bbl., or 68 per cent. of the total output. The amount produced under unit operation in the United States was negligible in quantity. Of the 420,896,000 bbl. produced in foreign countries, approximately 231,400,000 bbl., or 55 per cent. of the total, was produced under unit operation. The complete figures for 1929 are not available but the percentage of the total produced by unit pools in foreign fields was doubtless somewhat higher. It should be borne in mind that since the production from fields operated as units in many cases is restricted to market demands, the present production of these fields represents only a small percentage of the amount that could be produced if the fields were completely drilled and the wells were operated at full capacity.

In many of the foreign fields competition in drilling and producing operations is just as keen as in the United States and the methods followed in developing and operating the properties are not essentially different from those employed in our highly competitive fields. It is somewhat significant, however, that with the exception of the Lake fields in Venezuela practically all of the newer producing fields in foreign countries, and those that give promise of being extremely important in the future, are operated as units by single companies.

Classification of Oil and Gas Pools

For the purposes of this study oil and gas pools, both developed and undeveloped, are separated into four classifications which, for convenience, will be designated "unit," "near-unit," "cooperative" and "competitive."

Unit Pool.—This term will be applied in those cases where a single management controls the development and operation of the entire pool in such manner that surface property lines may be completely disregarded, and which will permit of utilizing to a maximum forces of expulsion native to the reservoir. A notable example is the Masjid-i-Suleiman (Temple of Solomon) pool in Persia.

Near-unit Pool.—This term will be applied in those cases where a single management controls and develops the entire pool or main part thereof, but in which control developments and operations are influenced by regard for conflicting royalty or lease interests so that oil and gas must be extracted at points determined to some extent by surface boundaries as distinguished from being influenced solely by reservoir content. A notable example is Salt Creek pool in Wyoming.

Cooperative Pool.—This term will be applied to those cases where several or many managements whose limitations are determined by surface boundaries control the development and operations in a single pool, but over which several managements there is a committee or some other authority named by them that regulates to some extent the rate and character of development and extraction from that pool. A notable example is the Yates pool in Pecos County, Texas.

Competitive Pool.—This term will be applied to those cases where several or many managements whose limitations are determined by surface boundaries, control the developments and operations in a single pool, but over which diversified managements there is no co-ordinating control except that which is imposed by practices and laws of the industry. Most pools in the United States come within this classification.

Reports were submitted by the respective regional chairmen on the status of unit operations in California; the Rocky Mountain Region; Kansas and Oklahoma; Arkansas, Louisiana, Texas and New Mexico; Appalachian Region, and foreign countries. These reports are summarized at length as individual papers in following pages of this volume and reference is made to them for further discussion.

Many members of the Division have contributed to this study and to these the Committee is particularly indebted. A list of contributors appears on pages 79 and 80. Special attention is called to the discussion (pages 81 to 104) following the Committee reports.

Future Scope of A. I. M. E. Unitization Study

E. L. Estabrook cooperated with H. H. Hill in accumulating and preparing material on Eastern United States and Foreign Fields. In addition the former prepared an analysis of the character continued study should take that justifies being quoted at length in this summary, and is as follows:

The New York members of the Committee were assigned the foreign correspondence as well as that covering the eastern United States and they soon found that the exchange of letters with the members in distant countries is a slow matter. Acknowledgments of the receipt of the questionnaire and advices that the writers are working on the problem are pouring in but the time available has not been sufficient to permit the foreign members to prepare their data and get them to us. The correspondence has at least given us a fair idea of the status of unitization in foreign fields and Mr. Hill has presented that information together with some brief descriptions of important operations, but a number of months will certainly pass before much of the information we seek will come to our hands.

The ideal of unit operation contemplates the development and exploitation of each oil pool by a single operator, or jointly by several operators who will develop and produce in accordance with a predetermined plan having as its objects the conservation of the hydrocarbon contents of the pool and the maximum ultimate profit to the owners. Popularly the term "unitization" has been expanded to include all of the partial steps that are being taken toward the ideal of unit operation, such as drilling and spacing agreements, cooperative repressuring and flooding, etc.

The profits to be derived from unitization are expected to come from three sources: (1) decreased expense of development and operation; (2) increased recovery and more complete utilization; (3) better prices for the product through elimination of distress selling in times of overproduction. The work of the A. I. M. E. Committee is particularly the collection and presentation of the facts concerning the first and

second expected sources of profit. Oil pools operated under single ownership are uncommon in the United States except on the Gulf Coast, but there are a number in foreign countries. Studies will be made of these unit-operated pools for comparison with other pools developed under competitive conditions in an attempt to arrive at some measure by which the economic advantages of unitization may be determined. The landowner who pools his holdings in a unit operation gives up his possibility of profit as the winner in the competitive fight and is entitled to know what benefits are likely to accrue to him as compensation for this forbearance. Are these savings really sufficient to warrant his entering the project, or must he depend only upon the hope of increased recovery and higher prices? What are the facts concerning the increased ultimate recovery that is reputed to follow unit operation? Is such increase a logical sequence of unit operation or does the lack of competition merely make it possible to apply improved production methods which might bring about increased ultimate recovery?

These are questions of fact for which the members of the A. I. M. E. may properly seek the answers. It is an engineering job and one for which we believe we are more competent than any other body of men. The unitization of oil pools is a big project involving many divisions of the petroleum industry. The rights of the landowners, the royalty holders and the lessees are affected; state or national legislation may be required; operating agreements must be devised which will take care of the changing prospectivity of adjoining acreage as the geological structure is made known by drilling; boards of appraisers and of operating engineers and geologists must be organized, and a multitude of other details require study and definition. There is plenty of work for a dozen committees on unitization from different organizations provided each will confine itself to that certain sphere in which it is most competent or will seek out and work upon phases of the problem that are not already being handled by a competent group.

There are disadvantages to unit operation as well as advantages. Men need the stimulation of competition if they are to do their best. Unitization may mean stagnation instead of progress. Short-sighted managements may fail to take advantage of the opportunities for sound economy which are created by unitization. Theoretically, unit operation makes possible an increase in the ultimate recovery of oil by repressuring during the early life of the field but there are few, if any, places where the method is being used. The fact is that crude oil is, and has been for several years, so cheap and so abundant that it has not generally been considered prudent business practice to invest large sums in compressor stations and other equipment for a prospective increase in production at some considerably distant date. Improved production practices which have accomplished some conservation without much additional expense have been welcomed but the industry generally has not made up its mind to spend real money on improved extraction methods. We must use care in estimating the advantages of unitization lest we count a number of conservation chickens that have not yet been hatched.

Among the foreign fields, Venezuela contains several well-known pools which are owned entirely by one company and which have been developed and operated without competition. Mene Grande is the oldest and most important, but El Mene, Concepcion and La Paz have been producing for a number of years. These pools are being studied to see if their development has been accompanied by a real saving of money and human effort over that which would have been expended in competitive development. Such a study involves a consideration of the factor of delayed return upon investment and may bring us face to face with that bugbear of "compound interest" which drives the miner to the rapid extraction of his ore and the factory owner to cutting prices in order that his plant may operate full time and keep down the fixed charges per unit of output.

Mexico offers us one of the best fields for comparative studies between competitive and noncompetitive operations. The "Golden Lane" is a 40-mile strip of oil-bearing territory with remarkably uniform conditions of surface terrain, depth of holes and character of reservoir. Certain sections were developed under the wildcat or competitive conditions, while other parts, where the land was held in large blocks, were practically unit operations. By making proper allowances for differences in subsurface conditions it is believed that some very illuminating comparative studies can be made on development costs and ultimate recovery under the two contrasting conditions.

Unit Operations in Eastern United States and in Foreign Countries

By H. H. Hill,* and E. L. Estabrook,† New York, N. Y.

(New York Meeting, February, 1930)

This report summarizes the information that was obtained by the Committee on Unit Operation in Eastern United States and in the foreign countries.

Letters and questionnaires were sent to all of the Eastern members of the Petroleum Division of the American Institute of Mining and Metallurgical Engineers and to those who are living outside of the United States, asking them to advise the Committee of any unit operations that are in effect in the various countries of the world and to furnish the names of men to whom inquiries should be directed for detailed information on the different projects. The response to the Committee's request is worthy of note. Practically all of the members who had knowledge of foreign operations replied to the questionnaire and not only furnished information that was of value to the Committee, but they evidenced a real interest in the subject of unit operations and assured the Committee of their willingness to assist in every way possible in order to make the study a success. The Committee wishes, at this time, to express its appreciation of the excellent cooperation that was received from the members of the A. I. M. E. to whom questionnaires were sent.

Unfortunately, the limited time that has been given to this survey did not permit the collection of detailed data on the different unit operations that are now in effect. It required several weeks to get back replies from the members located in some of the foreign countries and as a result the men who were asked to furnish information on the various projects have not had sufficient time to submit the detailed data that were requested. The Committee has been assured, however, that information relating to a number of unit operations will be furnished in the near future.

Part of the delay has been due to the fact that the purpose of the study was not understood and because the terms "unit" and "near-unit" operations were not clearly defined. In the foreign countries, practically all of the operations in noncompetitive fields are on concessions or leases that have been granted to a single company and for that reason

* Petroleum Engineer, Standard Oil Development Co.

† Petroleum Engineer, Pan American Petroleum & Transport Co.

do not represent consolidation of operating or royalty interests. The Committee has advised those requesting additional information on the purpose and scope of the survey, that data are desired for the purpose of showing the economies that can be gained by operating an oil or gas field under a single management or under operating agreements between several companies and the study is intended to cover all noncompetitive fields and all others in which some measure of control is obtained by cooperative agreements.

Inasmuch as it was not possible to obtain detailed information on the unit operations now under way in the various foreign countries, the present report gives only a brief summary of those in existence and an idea of their relative importance in the immediate petroleum picture of the world. The data that have been promised on the different projects will be embodied in future reports.

Eastern United States

According to the information that has been received, the only examples of unit or near-unit operations east of the Mississippi are furnished by a few prospective gas fields and by a number of repressuring projects. There are, however, several small pools operated by single companies and in some instances, no royalty interests are involved as the land is owned in fee by the operating company. In the repressuring projects that have been organized on the unit plan the companies pool their acreage and the operations are carried out by a single operating company. In a number of other repressuring projects the several companies operate their own properties but in accordance with a cooperative agreement between the companies involved. This plan has worked satisfactorily in many cases.

Examples of cooperation between companies as a means of reducing operating expenses and in limiting the number of wells to be drilled, are furnished by agreements between the gas companies in Southwestern Pennsylvania, the drilling of water wells on property lines in the Bradford field and in the well-spacing program that has been adopted in the Mount Pleasant field in Michigan. As a result of cooperative agreements, the gas companies operating in Southwestern Pennsylvania were able to shut in 270 wells, including 16 gas purchase contract wells, during the past summer in Armstrong, Allegheny, Washington, Westmoreland, Clarion and Green counties, Pennsylvania.

In the Bradford field in Pennsylvania and in the Allegany field in New York, all companies cooperate in the development of boundary lines for water-flooding by drilling the initial water wells along the property lines and dividing the cost equally between the adjoining operators.

In the Mt. Pleasant field in Michigan, where one company owns approximately 60 per cent. of the acreage, a spacing program of one

well to 10 acres and with wells 330 ft. from the property lines was initiated by that company and is being followed by the other companies in the field. This program represents a decided contrast to the exceedingly close spacing that was followed in the highly competitive fields near Saginaw and Muskegon where a large number of unprofitable wells were drilled and in the latter field immense quantities of gas were wasted before pipe lines could be constructed to consumers 2 miles away.

Unit Operations in Foreign Fields

North America

Canada.—In New Brunswick, an area of 10,000 square miles has been leased by one company and a producing field covering an area of approximately 3 square miles has been developed. About 100 wells have been drilled since the field was opened up and during 1928 approximately 8000 bbl. of crude oil were produced.

In Alberta examples of unit operation are furnished by three gas fields, two of which are operated by one company and one by another company. A prospective oil field in the same province will probably be operated by one company as a near unit.

Mexico.—One company operates two pools, the Filisola and Tonala fields on the Isthmus of Tehuantepec. These fields produced 2,415,000 bbl. in 1928 and it is estimated that the production in 1929 was in excess of 7,000,000 barrels.

A number of joint operating agreements have been made between companies in Mexico as a means of reducing costs both in the development and operation of properties.

South America

Venezuela.—The following important producing fields in Venezuela are each operated entirely by single companies.

Mene Grande, present production approximately	53,000 bbl. daily.
El Mene, present production approximately	5,000 bbl. daily.
La Paz-Concepcion, not producing at present.	

Other producing fields that are operated by single companies but which are not considered as major fields at the present time are: Rio Tarra, Rio de Oro and Guanoco. Possible fields that will be operated by single companies have been developed at Urumaco and Quire-Quire, but at present there is no outlet for the production from these areas.

In the competitive producing fields, along the eastern shore of Lake Maracaibo, the Ambrosia, La Rosa, Punta Benitez, Tia Juana and Lagunillas fields, the three companies interested have made joint agreements from time to time on well spacing and on other drilling and producing problems.

Colombia.—The two producing fields, Infantas and La Cira, are operated by a single company. The production from these fields in 1928 amounted to 19,895,677 bbl., an average of about 54,500 bbl. daily.

Peru.—The production in Peru is controlled by two companies, which operate in separate areas. In 1928 one company produced an average of 25,966 bbl. daily from one general district while the other company produced an average of 6523 bbl. daily from the other area.

Ecuador.—The production of Ecuador, amounting to approximately 1,090,000 bbl. in 1928, is practically all obtained from the properties operated by one company.

Argentina.—All of the important producing fields in Argentina are operated on a competitive basis.

Bolivia.—Although no production is being marketed from Bolivia, large concessions have been granted to two American companies and any fields that may be developed will no doubt be operated on the unit plan.

Trinidad.—Some of the smaller pools in Trinidad are operated as units while in the competitive pools there are large consolidated blocks operated by single companies. In many cases there are cooperative agreements between the companies on developing the boundaries of the properties. The Trinidad Government discourages competitive drilling by prohibiting the drilling of wells within 150 ft. of the boundary of a property and encourages centralized operations in the different areas by setting up "spheres of influence" around newly developed leases.

Europe

France.—The operations at Pechelbronn where oil mining is being employed are under one organization and can be classed as unit operations. The production of this area amounted to approximately 500,000 bbl. in 1928.

A small field at Gabain in the South of France is operated under the supervision of the Department of Mines, and although this furnishes an example of unit operations, the production of the field amounts to only a few barrels daily.

Germany.—The operations in Germany are competitive but an attempt has been made to consolidate a number of properties in one area that is now being tested.

Italy.—The four small producing fields are operated by single companies. There is no competition in the different fields as concessions are granted by the Government covering each producing area completely.

Rumania.—All producing fields in Rumania have been developed on a competitive basis as the land is divided into small plots seldom exceeding 100 acres, and in many cases as small as 2 acres. However, the companies

operating in the different fields cooperate in determining casing programs, spacing of wells and in the exclusion of water.

Poland.—Operations in Poland in the past, have been highly competitive but recently a joint company has been incorporated in which the Polish Government and the leading oil companies are participants. This company, known as the "Pioneer," will either engage in the exploration and exploitation of bituminous minerals, including petroleum, or will support the work of others through financial participation.

Russia.—All the fields in Russia are operated by a single agency, the Soviet Government. Under the new plan of development each sand is developed separately by drilling rows of wells around the entire pool and drilling new rows toward the center of the field as the edge wells become exhausted. The production of the different fields of Russia, for the year 1928, was approximately as follows: Baku, 57,655,000 bbl.; Grozny, 27,138,000 bbl.; Emba, 1,666,000 bbl.; Turkestan, Kuban, Black Sea area, 1,018,000 bbl.; total, 87,487,000 bbl. or approximately 240,000 bbl. daily.

Asia

Persia.—The oil fields of Persia furnish an excellent example of the advantages of unit operations. The fields are all operated by a single company and because of unit control it has been possible to limit the number of wells to the minimum required for draining the area, to produce the wells in the most efficient manner, and to restrict production to the market demands. The production of the Persian fields, of which the Maidan-i-Naftun is the most important area, amounted to approximately 40,000,000 bbl. in 1928, or about 110,000 bbl. daily, and this represented only a portion of the potential production.[1]

Irak.—Although important discoveries of oil have been made in Irak there is no outlet for the production at the present time. The field of I. P. C. will be operated on the unit plan as at present there is only one operating company consisting of British, French, Dutch and American interests.

India.—In the Assam and Punjab districts the several individual pools are each owned entirely by one company. The production from the Assam district in 1928 amounted to approximately 900,000 bbl. while the Punjab district produced approximately 350,000 barrels.

In the old Yenangyuaung field in Burma there are a number of hand-dug wells that are still operated by the land owners. Most of the newer part of the field is operated by a single company as is also a large part

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[1] An excellent discussion of Unit Operations in Persia was given by Capt. D. Comins at the December, 1928, meeting of the American Petroleum Institute. See Sec. III, *Proc.* 9th Annual Meeting, A.P.I.

of the Singu field. The production of the fields in Burma amounted to approximately 7,490,000 bbl. in 1928.

Dutch East Indies.—The several fields in Borneo, Java, Ceram and North Sumatra are operated by a single company. The fields in Sarawak are also operated on a unit basis. In South Sumatra there are two companies in the Palembang district, one a subsidiary of an American company, but these are operating in different fields. All the oil that is produced in the Dutch East Indies, therefore, can be considered as coming from fields that are operated as units. The production of the Dutch East Indies in 1928 amounted to 34,550,000 bbl. (approximately 94,700 bbls. daily) which was divided as follows: Borneo, 18,720,000 bbl.; Sarawak, 5,379,000 bbl.; Java, 3,498,000 bbl.; Ceram, 276,000 bbl.; Sumatra, 6,682,000 barrels.

Japan.—The production of Japan, which amounted to 1,773,000 bbl. in 1928, is practically all obtained from properties operated by one company.

Saghalien.—The operations on the Island of Saghalien are conducted by a Japanese company and by the Soviet Government. Although the area has been divided between the two interests, the operations are on different parts of the island and are, therefore, noncompetitive. The production of Saghalien in 1928 amounted to approximately 500,000 barrels.

Africa

The total production of Africa amounted to only 1,811,000 bbl. in 1928, of which approximately 1,800,000 bbl. were produced in Egypt and 11,000 bbl. in Algeria. The entire production of Egypt was produced by a single company. There are no producing fields in Africa south of the equator, but several wells have been drilled. If oil is discovered, the fields will no doubt be operated as units, as large concessions have been granted to the different companies.

Summary

The outstanding unit or single company operations outside of the United States are: the Tonala and Filisola fields in Mexico, the Mene Grande and El Mene fields in Venezuela, the Infantas and La Cira fields in Colombia, the fields in Peru, the Russian fields operated by the Soviet Government, the fields in Persia and the several fields in Dutch East Indies. These fields, together with the smaller ones mentioned, accounted for a production of about 231,400,000 bbl. in 1928, which was approximately 55 per cent. of the total of 420,896,000 bbl. produced outside of the United States during the year. The complete figures for 1929 are not available but the percentage of the total produced by unit pools was doubtless somewhat higher. There are other unit fields which are not important from the standpoint of the present world market for petroleum, but some of these will no doubt become of considerable impor-

tance in the future. It should be borne in mind that since the production from fields operated as units is in many cases restricted to market demands, the present production of these fields represents only a small percentage of the amount that could be produced if the fields were completely drilled and the wells were operated at full capacity.

In many of the foreign fields, competition in drilling and producing operations is just as keen as in the United States and the methods followed in developing and operating the properties are not essentially different from those employed in our highly competitive fields. It is somewhat significant, however, that with the exception of the Lake fields in Venezuela, practically all of the newer producing fields in foreign countries, and those that give promise of being extremely important in the future, are operated as units by single companies.

Unitized Operations in Oklahoma and Kansas

By A. W. Ambrose* and C. E. Beecher,† Bartlesville, Okla.

(New York Meeting, February, 1930)

It is the purpose of this paper to summarize data on unitization projects in Oklahoma and Kansas as obtained from replies to questionnaires sent out by the A. I. M. E. committee for these states. The information received indicates that unitization is growing rapidly in this area, but has not been in operation for a sufficient length of time to develop production history. It was impossible to obtain a record of all unitization projects in the time available. The magnitude of such projects is indicated by the fact that reports were received covering a total of 171,420 acres in Kansas and 49,350 acres in Oklahoma. Most of these units have been formed during the past 2 years, the greater number having been completed in 1929. It is anticipated that even more will be formed during the present year.

The following important facts have been emphasized by answers to the questionnaire and discussion with various operators:

1. Unitization is growing rapidly, as evidenced by the number of units and the large total acreage now included in units as compared with practically no acreage 2 years ago.

2. Operators are convinced that unitization is reducing development and operating cost and they anticipate greater reductions as experience is gained in unit operation.

3. Producing units have not been in operation for a sufficient length of time to give significant production history from which to estimate the ultimate recovery of oil, but the general opinion seems to be that more oil will be recovered.

4. In view of the benefits to be derived from unitization, many operators are refusing to carry on wildcat operations unless a unit has been formed. If this attitude continues to grow there will be no large pools developed in Oklahoma and Kansas in the future except under unit control.

Summary

The following tabulation gives a condensed summary of the information received on unit operations in Oklahoma and Kansas, but does not include all units, because many were not reported.

* Manager of Production, Empire Cos.

† Chief Production Engineer, Empire Gas & Fuel Co.

	Oklahoma	Kansas
Number of units reported	27[a]	30[b]
Total acreage	49,350 acres	171,420 acres
Smallest unit	320 acres	400 acres
Largest unit	10,080 acres	28,000 acres
Average acreage per unit	1,828 acres	5,714 acres
Average number of companies per unit	4.7	3.3
Companies per unit	3–10	2–9
Form of agreement	Committee[c]	Committee[c]
Producing units	9	3
Nonproducing units, not tested	13	19
Nonproducing units on which dry holes have been drilled	6	9

[a] Does not include three units reported without acreage.
[b] Does not include one unit reported without acreage.
[c] One contract to test acreage.

Oklahoma—Summary by Counties

Seminole County

10 units; average acreage, 565.
3 units producing, 4 units being tested and
3 units have been tested adversely.
The last three units were formed because of the short term of the leases.
A considerable saving was made by each of the companies involved, in that only one dry hole was necessary to test the block.

Pottawatomie County

4 units reported, acreage involved in one not given.
2 units—average acreage, 515. Test well drilling on each unit.
1 unit of 6000 acres on which one dry hole was drilled.
Not known whether unit is to be tested further before abandonment.

Hughes County

2 units; average acreage, 460.
1 unit. One well completed and second drilling.
1 unit. Two gas wells completed.

Woods County

2 units; average acreage, 9680. Each being tested.

Payne County

2 units; average acreage, 980.
1 unit. One 300-bbl. well and second well drilling.
1 unit. Eight oil wells and 2 dry holes have been completed.

Lincoln County

3 units, 640 acres in each.
Dry hole drilled on one, well drilling on second and one 75-bbl. well completed on third. There are four to six operators in each unit.

Greer County

1 unit; 8000 acres; well drilling.

Noble County

1 unit; 2560 acres; well drilling.

Pontotoc County

1 unit, 1330 acres.

One well completed and three dry-hole offsets. It is possible that more dry holes would have been drilled as a result of the initial well had not the acreage been controlled by a unit.

Osage County

1 unit; 480 acres; not tested.

Logan County

1 unit; 680 acres; dry hole drilled.

Kansas—Summary by Counties

Butler County

4 units; average acreage, 560.

2 units; dry and abandoned.

2 units; well drilling.

Sedgwick County

3 units; average acreage, 4300 acres.

1 unit, producing; 63 wells.

2 units; dry and abandoned.

Rice County

4 units; acreage on one not known.

8160 acres average for three units. Well drilling on each unit.

Summer County

2 units; acreage on one not known; 640 acres other unit. Well drilling on each unit.

Elk County

1 unit; 640 acres, well drilling.

Russell County

3 units; 3006 average acreage. One unit undeveloped, one dry, one producing.

Rooks County

1 unit; 1760 acres undeveloped.

Reno County

1 unit; 640 acres undeveloped.

1 unit; 24,000 acres. One well; one drilling.

Rush County

2 units; average acreage, 2800. Well drilling on each unit.

Edwards County

1 unit; 15,000 acres. One well producing oil and gas.

Barton County

1 unit; 7,560 acres. Well drilling.

McPherson County

2 units; 5250 average acreage.

Well drilling on one, other dry and abandoned.

Cowley County

1 unit; 880 acres; dry and abandoned.

Pratt County

1 unit, 3000 acres; no development.

Stafford County

1 unit. No information as to development or acreage.

Ellis County

1 unit; 5000 acres; dry.

Barber County

1 unit; 28,000 acres; dry.

Dickinson County
1 unit; 4500 acres drilling.
Ford County
1 unit; 11,600 acres drilling.

Type of Contract

Within the last year the Mid-Continent Oil & Gas Assn. has been active in promoting and encouraging unitization. Through its committees several types of unit operating contracts have been prepared, one of which can be made to apply to almost any set of conditions if the operators really wish to form a unit. These contracts are known as the Committee, Trustee, and Adjustment Forms and all provide for a single operator. In case one of these contracts can not be made to apply a form has been provided for "Agreement for Cooperative Development and Operation" in which each operator agrees to conform to a plan of development and operation. This latter plan falls short of unitization, but makes an effort to approach it and is far better than no cooperation.

The Committee form of contract is most popular. With one or two exceptions all of the unitization projects reported are operating under this form with minor changes to meet special conditions. The contract provides for the assignment of undivided interest in the leases making up the unitized area so that each of the parties shall have title to an undivided interest in the unitized area in the proportion that each party's present interest in the acreage bears to the whole. One of the parties is usually selected as the operator and each party has a representative on the Advisory Committee, with a vote in proportion to the interest he represents.

Producing Units

Sketch maps have been prepared to show a few unitized areas on which production has been obtained and to outline briefly a few points regarding each unit.

Fig. 1 shows a portion of a pool in Kansas, which was combined into a unit. There were only three operators included in this unit and it is understood that one of them had no acreage at the time of forming the unit but was given an interest in the block for drilling the initial well. One company owned the major portion of the acreage in the unit which it acquired as the result of core-drill information. The outline of leases is shown on the map. It is evident that unitization has prevented a widespread drilling campaign, which usually follows a discovery of this character, and the many dry holes resulting from such a drilling program. A large flush production was also prevented.

Fig. 2 is the outline of a unitized pool in Oklahoma, showing the individual leases and those included in the unit. This pool was located

as the result of core-drill tests and a unit was formed based on the possible limits of the pool. The productive area, however, was limited to only a few wells, most of which are on the leases owned by one of the three companies in the unit. At first, this might appear to be a hardship on the company owning the leases, because 15⁄33 of the production must be credited to the other two members of the unit, but this company does not consider it so for it is interested in other unitization projects

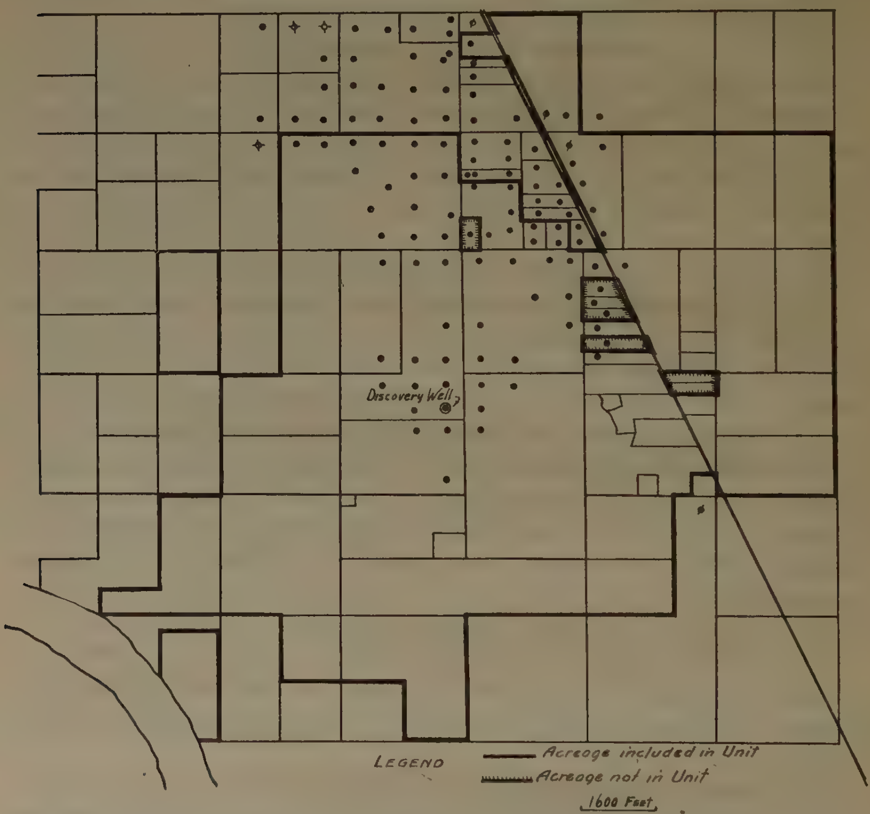

Fig. 1.—Portion of Kansas pool combined into unit.

and believes that in a series of such unit operations these conditions will be equalized. The savings resulting from the elimination of competitive drilling may have decreased development costs to such an extent that the company has actually made a profit on this unit.

Fig. 3 is the outline of a unit pool in Oklahoma in which the total gross production to Jan. 31, 1930, has been over 1,000,000 bbl. The unit consists of 640 acres divided into 12 different leases, originally owned by eight different operators. It is estimated that at least eight additional

dry or noncommercial wells would have been drilled in this area had it not been unitized. In this connection it is interesting to note the dry holes drilled around the center of sec. 10 to the west of the unitized block. These wells were drilled two or three years ago. Had the area been unitized it is safe to estimate that over one-half the cost of the dry holes could have been saved.

If the leases were being developed individually there would be several gas-lift plants. Under present conditions one gas-lift plant is expected

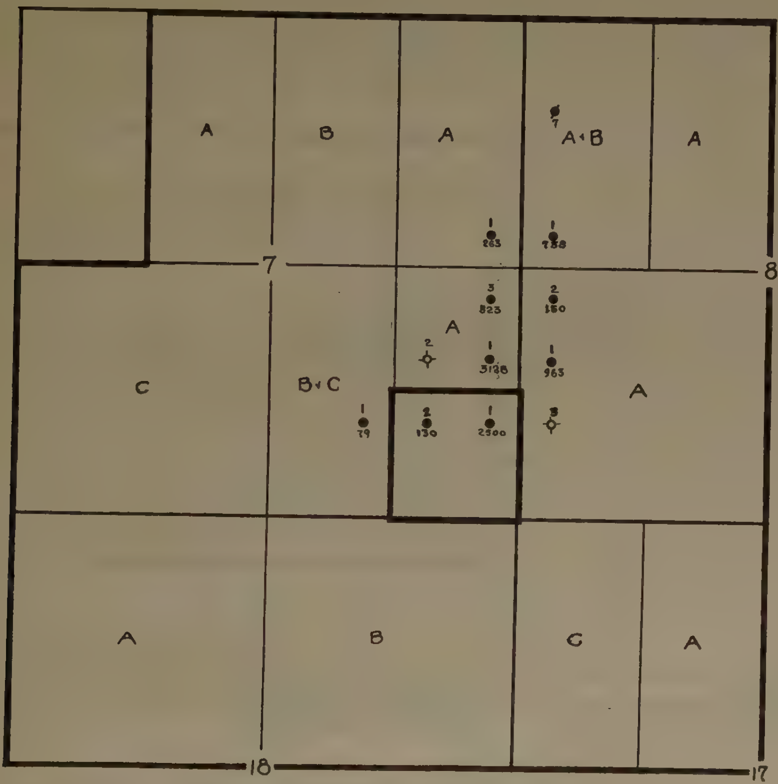

FIG. 2.—UNITIZED OKLAHOMA POOL.

to handle the operations and the extraction of gasoline is taken care of for the entire unit. Cost of development has been reduced by operating only a few drilling outfits at once. This has also reduced the cost of water and gas and the necessary piping. Low operating costs are anticipated because only a small personnel and overhead will be required. Because of unitization, repressuring operations may be profitable in the area at some future date, while under divided ownership this would not be considered.

NONUNITIZED DEVELOPMENT

A few sketches have been prepared for the purpose of showing a contrast in development between unitized and nonunitized areas.

Fig. 4 shows development of a nonunitized pool in Kansas. The outstanding feature of this development is the large number of drilling wells and the few producing wells. At the present time there are 6 producing wells, 50 drilling wells, 15 different operators, and development started on 23 different leases. The discovery well has been abandoned because of mechanical troubles and a twin well is now being drilled. If this pool had been unitized, there would be only one operating instead of 15 and possibly 5 or 6 strings of drilling tools instead of 50. Under the present development program many dry or unprofitable wells will be drilled, many of which could be eliminated if unit operation were in effect.

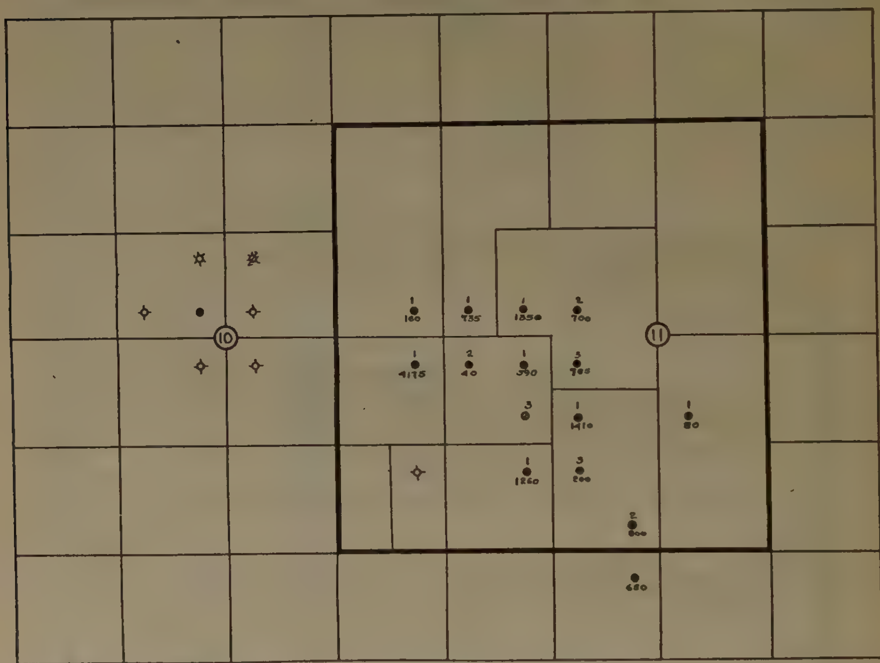

FIG. 3.—UNITIZED OKLAHOMA POOL; TOTAL GROSS PRODUCTION TO JAN. 1, 1930, OVER 1,000,000 BARRELS.

No effort has been made to estimate the savings in development and operating cost of this pool under a unitization plan as compared with the present plan, but it is safe to estimate that these savings would be several million dollars.

Fig. 5 shows two maps of the same pool, one as actually developed and the other as development would have been under unitization. The date of completion is shown for the discovery well and the date of starting for the other wells. The expiration date is shown for each lease.

In the area under consideration there are 800 acres, divided into 13 leases owned by 11 different operators. A total of 21 oil wells and 4 dry holes have been drilled and one well is now drilling.

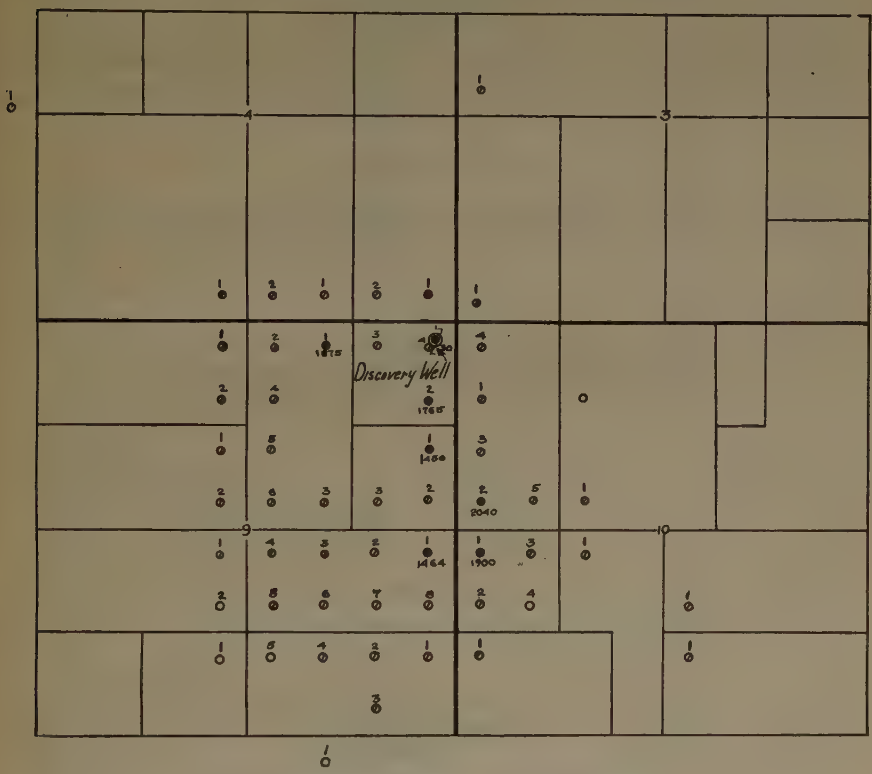

Fig. 4.—Nonunitized pool in Kansas.

If the pool had been unitized it is estimated that only 9 wells would have been drilled to date—8 oil wells and one dry hole. The location of the wells is shown on the map. The discovery well would have been drilled on the first lease to expire and after its completion as a commercial producer 3 offset wells would be required. The leases in the northeast and southeast corners of the unit would require development next because of expiring leases. A producing well would have resulted from drilling in the southwest corner of the northeast lease. The three offset producing wells would then be drilled. The well in the northwest cor-

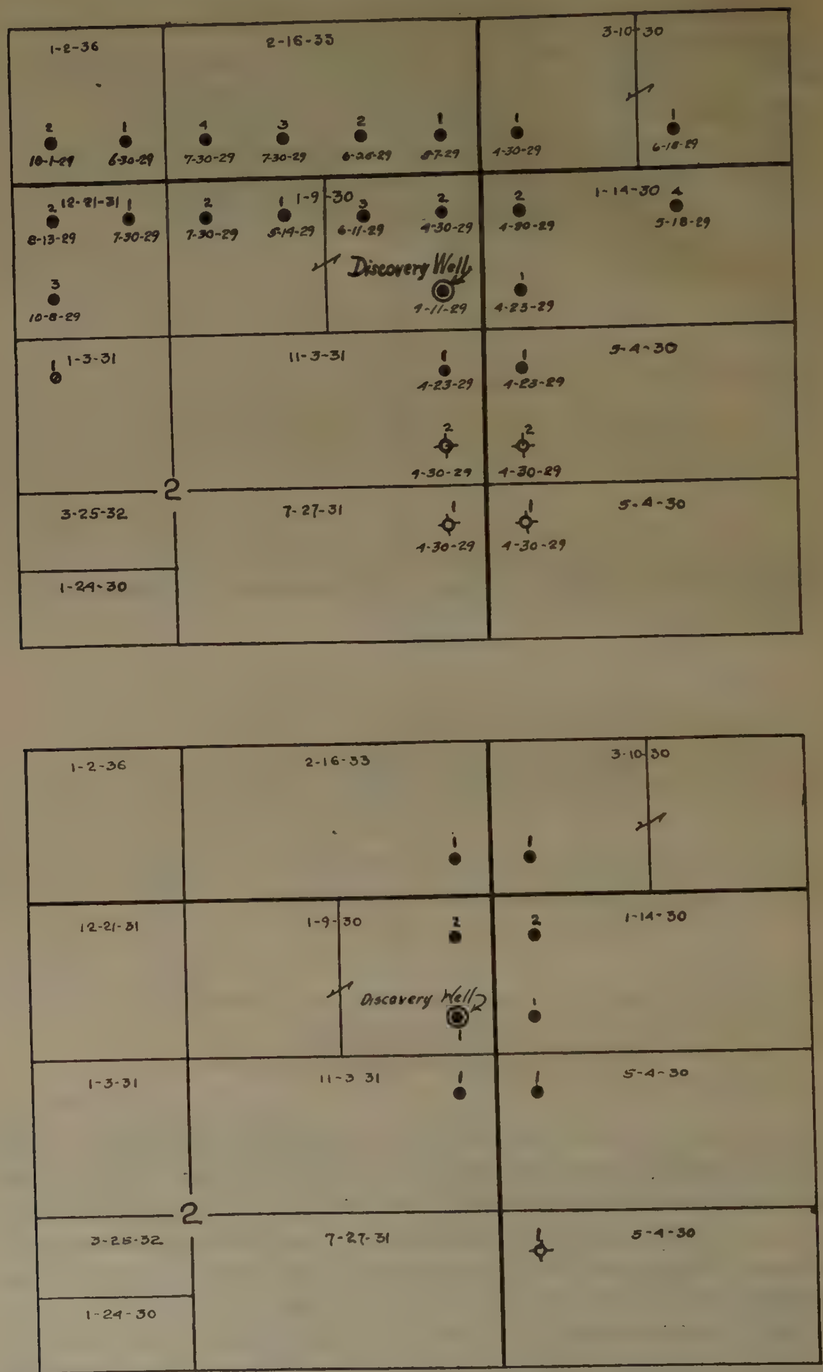

Fig. 5.—Two maps of same pool; top, as actually developed; bottom, as development would have been under unitization.

ner of the southeast lease would have been a dry hole. With this information available three dry hole offsets would not have been drilled.

The present development as a whole has not been profitable. It is estimated that eight leases on which wells have been drilled will not pay out, one lease is questionable, but may produce enough oil to pay out, two leases will pay out and probably make a small profit on the investment, and one small lease has already paid out.

Some figures have been prepared to show the estimated status of the pool as of Jan. 28, 1930, as developed and what it might have been under unitization. The figures indicate that unitization would have greatly reduced the investment and the present net production while being smaller, would have cost much less per barrel.

As Developed

26 wells @ $60,000	$1,560,000	
Miscellaneous investments @ $7,500 for each producing well	157,500	
Total investment		$1,717,500
Production		
762,134 gross bbl.		
66,867 net bbl. @ $1.60	1,066,987	
Operating expenses @ 20 c. per bbl.	133,373	
Net earnings		933,614
Balance to pay out		783,886
Present production:		
Gross, 2,810 bbl.; net, 2,460 bbl.		
Present cost per net barrel based on unretired portion of investment		319

Estimated Unitized Development

9 wells @ $60,000	540,000	
Miscellaneous investment @ $7,500 per well	67,500	
Total investment		607,500
Production:		
449,775 gross bbl.		
393,553 net bbl. @ $1.60	629,685	
Operating expense @ 20 c. per bbl.	78,710	
Net earnings		550,975
Balance to pay out		56,525
Present production:		
Gross, 727 bbl.; net, 636 bbl.		
Present cost per net barrel based on unretired portion of investment		$ 89

Unit Operation and Unitization in Arkansas, Louisiana, Texas and New Mexico

By F. H. Lahee,* Dallas, Texas

(New York Meeting, February, 1930)

Questionnaires and special letters soliciting information were sent to a great many geologists, petroleum engineers, independent operators, and representatives of large companies in Arkansas, Louisiana, Texas and New Mexico. Replies to more than 50 per cent. of these letters were received. A survey of the facts and opinions presented in this correspondence will be made a little later, but first some of the general aspects of the problem will be reviewed.

By "unit operation,"[1] we mean the development and operation of a single entire pool, or reservoir, of petroleum by one management, on a systematic and scientific plan which is best calculated ultimately to extract from the pay sand and bring to the surface of the ground the largest possible amount of oil with the greatest possible total profit.

No one, as far as the author has been able to ascertain, denies the advantages, both scientific and practical, of unit operation. All are agreed that it is sound in theory. It permits the proper distribution of wells, which should always be spaced on the ground according to a regular geometric plan with the intention of maintaining the same spacing all the way down and into the pay sand, or pay sands. This spacing will be different for different fields, depending on such variable factors as the lithologic character of the pay formation, the nature of the controlling structure, the depth of drilling, the viscosity of the oil, and so on. From the viewpoint of engineering practice, as applied to economical extraction of oil, there is no more important consideration than well spacing—well spacing in the pay formation, and not merely on the surface of the ground—for the method of well spacing has a direct bearing upon all such engineering practices as pressure control, repressuring by gas, the water drive, and so on.

H. C. Miller[2] summarized the advantages of an ideal cooperative development plan as follows: "Among the more important advantages of

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* Chief Geologist, Sun Oil Co.

[1] See I. L. Dunn and J. O. Lewis: Advantages of Unit Operation in New Pools. Petroleum Development and Technology in 1926, A. I. M. E. (1927).

[2] H. C. Miller: Function of Natural Gas in the Production of Oil. Amer. Petr. Inst. (1929) 253.

an ideal cooperative development plan, with particular reference to proper utilization of reservoir gas energy, are the following: (1) a carefully planned development program is made possible, by which unnecessary offsets, too close spacing, and other evils of competitive drilling may be avoided; (2) overproduction in any one area is prevented, making proration or shutting in of production easily accomplished; (3) the shutting in of wells which have excessively high gas-oil ratios is made possible, the application of gas injection processes can be made at the best points without regard to lease boundaries, and uniform pressure control can be exerted without danger of loss of production; (4) exchange of information is facilitated and the most efficient engineering control is made possible at moderate cost. Aside from the advantages directly concerned with the conservation of reservoir gas energy it will (5) make possible the reduction of overhead and operating costs through the reduction of personnel and elimination of duplication of equipment; and (6) facilitate repair work on wells and means to combat water encroachment."

Existing Units and Near Units

In the south Mid-Continent area, including the states of Arkansas, Louisiana, Texas and New Mexico, there are many examples of blocks of leases, or of single large leases, held and operated by a single company. From the technical point of view these may be unit operations, but they do not involve the same difficulties of cooperation which affect blocks of multiple lease ownership. The principal obstacle to unit operation of blocks held by one lessee is encountered where the leased acreage includes many royalty and fee ownerships.

No pertinent data relating to the economic aspects of unit operation of blocks under lease to one company have been secured. This is chiefly because so few such blocks have been drilled that comparative cost and profit figures are not available.

In regard to unit operation of blocks held by two or more lessees, let us consider the four states in order. In Arkansas two such unit operations were reported. In one case the leases, which total over 1100 acres, are checkerboarded over a structure in tracts of from 10 to 80 acres. They are owned by two companies on a 50-50 basis. One of these companies has done all the drilling. In the other case a solid block of 920 acres, at first leased separately to six companies, was unitized for the drilling of a test well, which proved to be dry. One of the six companies was elected as operator to drill the well, and all six contributed toward the cost in proportion to the size of their respective original holdings. After the test was abandoned as a dry hole, the joint operation was dissolved. In neither of these cases was any difficulty experienced in bringing about the mutual agreement or in carrying out the drilling program.

In northern Louisiana there are no unit operations of oil pools. Efforts have been made to unitize the Richmond and Monroe gas fields, but without complete success.

In the Gulf Coast district of Louisiana and Texas, and in East Texas, at least 30 salt domes are partly or wholly included in blocks of leases in which two or three companies participate. On several of these drilling is in progress.

In other parts of Texas there are many small blocks and several large blocks in which unit operation has been carried on successfully. Important among these are the Comanche block, in Comanche County, comprising 33,000 acres owned by 10 participants; the two Overall blocks in Coleman County, one consisting of 328 acres and owned by five lessees, and the other consisting of 2057 acres and owned by five lessees; a unit operation in south Ector County, in which there are three participating companies; a block of 10,000 acres in Andrews County, with three companies participating; a block of 10,000 acres in Kent County, with four companies participating; and a block of 9 square miles in Loving County owned by five companies. On all of these drilling has been, or is, in progress.

In southeastern New Mexico there is no unit operation. One attempt failed because of special drilling obligations. An effort among the operators to bring about curtailment of drilling in the Hobbs area, in Lea County, was abandoned after notice was served by the Commissioner of Public Lands that "so long as this state (New Mexico) produces but a small part of its consumption, no scheme of prorating or shutting in could properly apply."[3]

A few of the outstanding examples of unitization and proration in Texas should be considered in more detail, chiefly from the point of view of organizing the cooperative program. In this connection unit operations on lease blocks in which only one or two concerns participate are not of particular interest.

Probably the oldest unit operation in the part of Texas outside of the Gulf Coast was on the larger Overall block in Coleman County, which is described by H. H. King[4] as follows:

> The pooling of acreage for development by one field organization . . . originated through the efforts of the owners of the discovery well to have an understanding with offset lease owners regarding the spacing of wells and the conservation of gas pressure on the sands. M. G. Cheney, Fort Worth geologist and operator, Continental Oil Co. and the Anzac Oil Corpn., opened the field through the completion of their M. T. Overall 1-C, located on the west line of sec. 12, O. W. Watson survey. Cheney, president of the latter concern, conceived the idea of the acreage pool through having

[3] *Oil Weekly* (Nov. 1, 1929) 24.

[4] H. H. King: Unit Operation Plan Gains Wide Acceptance in Texas. *Oil Weekly* (Dec. 13, 1929) 58.

just previously attended a meeting of petroleum engineers that brought out the advantages of unitization. Support of several near-by lease owners was gained by Cheney, and the latter cooperated in selling the idea to the owners of other leases that were desired to be included.

Four companies taking part in this unit plan contributed 2057 acres of surrounding leases to the pool in late March, 1928, with the percentage of ownership in the entire block distributed as follows: Cheney-Anzac interests and the Continental Oil Co., 36½ per cent. each; Mid-West Exploration Co., 18 per cent., and Humble Oil & Refining Co., 9 per cent. Since the former two interests contributed an oil producer and two completed gas wells along with their acreage, it was necessary to appoint a committee to equalize the value of the various properties and fix the percentage interest of each member by a per acre ratio. The owners of the discovery well and gas wells were reimbursed for previous expenditures.

Continental Oil Co. was elected to operate the properties, assisted by a committee to dictate the development policy . . . any member of the plan has the right to consume its own share of the production.

The second Overall unit plan, covering 328 acres, was organized for exploration work on a group of short-time leases that were considered doubtful for production, but which were subsequently proved to be prolific. This is mentioned primarily to emphasize the inducement for unitization. Not infrequently willingness among the operators to unitize their holdings has been intensified either by the fact that none of them feel justified in shouldering the entire cost of a test well under the known geological conditions, or by the fact that leases other than the tract on which the first well is drilled will expire before a second well can be drilled in the event that the first well is a producer.

The Comanche block is worthy of special notice because of its size (33,000 acres), the number of participants (10), the entire absence of commissions, and because of the low cost of the project as a whole. The 10 interests subscribed $4000 each for an undivided 10 per cent. share in the block, making sufficient capital to pay off on the leases. For each test drilled, $2000 is to be subscribed by each member. The tests are to be drilled, and a third at the option of the Committee, which includes a representative of each participating company. One of the participants was elected Operator. It is the duty of the Committee to govern the operations, acting in an executive capacity. It is the duty of the Operator to carry out the practical details of management and development. Each member of the plan will be privileged to consume its tenth of any oil or gas produced.

An important unit operation now in progress is the Van project in Van Zandt County, East Texas.[5] In this case, as in the larger Overall project, consummation of the plan was brought about in order to systematize drilling and production through a cooperation plan of well spacing

[5] *Oil Weekly* (Nov. 8, 1929) 30; (Nov. 29, 1929) 71; also *Natl. Petr. News* (Nov. 20, 1929) 51.

and gas conservation. The plan affects a solid block of nearly 6000 acres which has been outlined as closely as possible, while still following land lines, in conformity with the shallow subsurface structure plotted on scattered core-hole data. Within this block, the acreage holdings are such that the five participating companies own the following fractions of the whole, respectively: 81.70, 7.75, 4.51, 3.57 and 2.47 per cent. The company having the major interest is operating the property. All five participants will share in costs and profits on the basis of their fractional interests. For a time these interests will be tentatively based on the amount of acreage originally held by each company, but after there has been time to accumulate data for constructing satisfactory production decline curves, readjustment of this schedule will be made, based on the ratio of estimated ultimate productivity of the leases owned by each party to the estimated ultimate recovery of all the leases in the block, and readjustment of costs and profits will be retroactive to the beginning on the new schedule. In this manner the owners of the more productive leases will in the end reap proportionally greater profits per acre than the owners of the less productive leases. In other words, the parties will benefit in proportion to the more or less fortunate position of their leases in the pool. By this method one of the objections often raised to unitization is removed, the objection that pro rata distribution of profits based only on acreage may reduce the income of those leaseholders who own the most productive tracts.

Another point worthy of note is that the Van unit plan concerns the pay horizons covered in the agreement. The present operation relates particularly to the Woodbine sand, but not to pay zones which lie below the base of the Upper Cretaceous, *i. e.*, below the Woodbine formation. If oil is discovered in paying quantities below the base of the Upper Cretaceous, it is to be developed entirely independently of the upper oil pays, as if it occurred in a separate oil field, but the operations for producing such deeper oil are to be governed after the same manner as those for the Woodbine oil.

For the final systematic development of the pool, a regular well spacing has been planned, with one well to approximately every 5 acres. From the total number of proposed locations, those are selected for the first campaign of drilling which seem best adapted to test the many leases, with one well and in a few instances two or three wells to each fee ownership. These locations are chosen in pairs of offsets, rather than as single inside locations, and the pairs are distributed over the block as uniformly as possible.

The whole endeavor in the Van agreement has been to make an equitable arrangement for all those concerned, operating companies, land owners, and royalty owners, alike, and, at the same time, to control production by a systematic method development, and thus make larger

profits for all than could be secured if the field were drilled on a competitive plan.

The most interesting example of proration in Texas is that of the Yates pool, in Pecos County,[6] which extends over about 16,000 acres, and is leased to 17 operators. In December, 1929, there were about 350 producing wells with a total potential daily capacity between 1,500,000 to 2,500,000 bbl., but with a total daily capacity restricted to 136,000 bbl. Potential capacities of individual wells range from 25 bbl. per day to 8530 bbl. per hour. The state of Texas holds an interest in the mineral rights under some of the leases and requires that offsets be drilled to all wells within 1000 ft. of the boundaries of these leases. The following is quoted from a letter:

From Oct. 1, 1927 to Jan. 1, 1928, the oil runs were prorated according to the total potential capacity of all wells that the several operators had in the field. Potential capacity of the wells was measured by one hour's open flow gage. All oil run to storage by an operator was deducted from his daily allowable run.

It was proposed to limit drilling to one well per 40-acre unit when this plan was adopted, but fear of litigation, arising out of the anti-trust laws, led to rejection of this limiting clause.

This plan put a premium on drilling, especially in the areas with high productive capacity, and it soon became apparent that the proration plan would have to be changed to correct this fault.

From Jan. 1 to Aug. 1, 1928, the oil runs were prorated according to total acreage held by the several operators within the limits of proved acreage, as determined by a consulting geologist employed by the proration committee for this purpose. A few arbitrary adjustments were made to compensate operators, all of whose acreage had much higher potential than the average potential of the field; but serious discrepancies developed under this arrangement.

The following plan was agreed upon, in August, 1928, and is still in operation: Each operator's acreage is divided into 100-acre units; 25 per cent. of the oil run is prorated according to acreage and 75 per cent. according to the average potential of all the wells on the unit. Each unit must produce all the oil allocated to it and the offset wells of neighboring operators are produced ratably to their potentials.

At the invitation of the operators, the State Railroad Commission issued an order placing the field under proration according to this plan and the proration is administered by the Commission. The proration plan and the details of operation were worked out by a committee of the operators.

Except for two areas where closer spacing of wells resulted under the first proration plan, the average spacing is about one well to 55½ acres. This spacing and the present rate of production appear to be satisfactory for the greater part of the field. There has been no appreciable change in the open flow potential of the wells and in the rock pressure in the more porous, or more permeable, area. This indicates that here the oil is being replaced by water at the edges as rapidly as the oil is withdrawn. In other words, the oil is here produced under hydrostatic control. There is no evidence of uneven advance of the edge water.

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[6] *Oil & Gas Jnl.* (May 24, 1928) 34; (June 28, 1928) 47; also *Natl. Petr. News* (June 27, 1928). An excellent summary on unitization was printed by the *Oil Weekly* (Dec. 7, 1928) 51–86.

Under unit operation . . . withdrawals of oil would be somewhat more equally distributed . . . than they are now, but there would be no great change in this respect. The present distribution of the withdrawals is not far from being completely satisfactory from an engineering point of view. Eventually the field will need many more wells to drain it properly.

One rather serious feature, which would be eliminated under unitization, is the making of periodic open flow tests to govern proration readjustments. This may be corrected under the proration. A committee of company engineers has conducted tests for some time and has worked out a method for determining the potential capacity of wells under restricted flow, which appears to be more equable than the open flow test.

I have discussed the operation of the Yates field under the proration agreement at some length because this is the outstanding example of successful operation under such an agreement. The fact that the phenomenal productive capacity of the wells forced the operators into an agreement to avoid disaster, does not detract from the credit due them for their diligent and enlightened effort to arrive at an equitable plan for dividing the outlet to which all could subscribe. They deserve especial commendation for their efforts to hold the rate of production at so low a figure. Because of this agreement the Yates field is yielding higher returns on the money invested than any other field in the country and will continue to do so for a long time. This is in marked contrast to some other West Texas fields where proration was applied in a rather half-hearted manner.

In the Hendricks pool in Winkler County, in the Chalk-Roberts pool in Howard and Glasscock counties, in the Darst Creek pool in Guadalupe County, and in the Bowers-Finley area in Gray County, all in Texas, proration agreements are in effect for curtailing production. These plans cannot be described here.[7] One correspondent, a member of the proration committee for the Chalk-Roberts pool, says: "Our proration committee functioned from the time that the first competitive operations began but the initial well had produced for a few weeks prior to that time. The results were very satisfactory from the standpoint of the individual operators and we were able to quiet opposition to our various plans long enough to demonstrate their value. One of the greatest difficulties that we encountered resulted from the fact that many of the individual operators were suspicious of their larger and stronger neighbors. However, I can say positively that these suspicions were not justified by subsequent experience."

Opinions for and against Unit Operation

Some of the objections to proration are (1) that there is no power to enforce adherence to the agreement; (2) that certain companies may have to fulfill oil delivery contracts; (3) that there is fear of future lawsuits based on the law concerning agreements in restraint of trade; (4) that injury to the wells may result from the required methods of

[7] See various articles in the trade journals, especially *Oil Weekly*, *Oil & Gas Jnl.* and *Natl. Petr. News*.

gaging and handling; (5) that certain buyers of crude may prefer the oil from one field rather than the oil from other fields. "However effective the proration method may be," writes Robert E. Allen,[8] "it serves only to alleviate an unsound and dangerous condition, which under our present system of development may recur at any time the hand of control relaxes. . . . Only two fundamental plans for the permanent betterment of the industry have been presented. One plan provides for government regulation and control, which needs no comment; and the other calls for unit operation, or, as it may be called, unit cooperation."

Unit operation appears to be working well in several localities in Texas, but a majority of the participants are major companies. From the smaller independent operators various objections are raised. We should take cognizance of their attitude and in all attempts at unitization we should try to be absolutely fair. Following are some of the opinions expressed in reply to a letter which was sent to 40 or 50 independent operators:

All independent operators and officials of small companies agree that the unit plan will not work out in practice. It will inevitably eliminate these operators. The independent, if he strikes oil, and has leases to sell, can obtain more money for his leases than for a small undivided interest in a large block. He can drill more cheaply than a big company, because his overhead is relatively small. He will have no control over operations. He may be forced to postpone development, if the major interests so vote, or he may be forced to contribute his share toward expenses possibly at times when he cannot afford to do so. He must relinquish his independence.

On the other side, we would point out that the independent operator gains several important advantages in unit plan development, not the least of which are the more certain market available for the oil, the larger ultimate profits, and the opportunity to benefit by the experience of the trained technical and production departments of the larger companies participating.

Not all the independent operators have misgivings about the practicability of unit operation. In fact those who are most apprehensive are those who have not given it a trial. M. G. Cheney, an independent operator, who has participated in at least three unit operations, expressed himself in this way: "Our experience has been very satisfactory and I highly endorse the movement." Another independent operator wrote thus:

> From an engineering standpoint, there is such a terrific waste in such fields by reason of drilling excessive wells to protect offsetting lines and with ensuing loss of oil by careless and greedy drilling, that it seems that the operators with even a fair degree

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[8] *Oil Weekly* (Feb. 7, 1930) 25.

of intelligence should be able to get together on some sane policy to eliminate the useless expense of drilling useless wells and the ensuing extra cost of operation after the wells are drilled and with a less recovery of oil per acre. It would seem that sensible people should find some common ground to work on.

I believe also that with proper education the royalty holders can be induced to take a more sane and liberal view if the trouble is taken to show them that it is not a scheme to beat them out of their royalty and that by proper drilling from an engineering standpoint, a greater amount of oil can be recovered per acre.

There are many different angles to a situation of this kind that would have to be approached in a broad generous way with due regard for the rights of the other fellow.

We all want to play fair and allow everybody to have his opportunity. No one will deny that many complications arise, and it is only through practice in modelling agreements and experience in carrying on operations under these agreements that we can gradually evolve the best methods for all concerned.[9]

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[9] For an outline of a model form of contract for unit operation, see *Natl. Petr. News* (July 4, 1928) 84.

Study of Unitization in the Rocky Mountain Region

By F. E. Wood,* Casper, Wyoming

New York Meeting, February, 1930)

Since the earliest discoveries of oil in the Rocky Mountain area the spirit of cooperation in drilling and production programs has prevailed. There has scarcely been a field which has not been developed in an orderly manner through mutual agreement between competitive operators. An appreciable saving has resulted, as many unnecessary wells have been eliminated. We have unit operation plans and agreements which were developed at an early date. Rock River, found in 1918, has been a unit operation. One of the first prorate agreements ever attempted was made in Salt Creek in 1921. Teapot, first developed in 1922, has been a unit operation; the lessee, the Government, and the lessor, one operator. South Casper Creek, found in 1918, has been developed as a unit. Rex Lake, found in 1923, is a unit operation. The list might be extended materially but it serves to indicate that the Rocky Mountain region enjoyed the fruits of unit operation at an early date.

It is concluded from this unitization study in the Rocky Mountain region that there is an appreciable saving in both development and production costs as well as the elimination of waste of a natural resource. Certainly, when unit operation conserves an irreplaceable natural resource as well as capital, any legal or political impediment to its successful development will be overcome.

If one company supervises the operations in one field, it appears to be a unit operation. This may not be true if the lands involved have been leased from a great number of lessors. Royalty holders create a most intense competitive operation. The Rocky Mountain region has its full quota of such diversified interests.

The original study calls for consideration of two types of fields, unit and near-unit operation. This Committee has felt that if an agreement of any character has brought about a saving it is an approach to unit operation. The fields have been classified into four types:

1. *Unit Operation.*—Any field whereby the competitive drilling-drainage feature is or will be absent in the development and operation of the pool.

* Petroleum Engineer, Midwest Refining Co.

2. *Near-unit Operation.*—Any plan whereby the competitive drilling-drainage feature is or will be reduced or regulated in the development and operation of the pool.

3. *Cooperative Agreements.*—Any agreement whereby production is prorated, expenses pooled, drilling programs mutually curtailed, and so forth.

4. *Undeveloped Fields.*—Any plan which is in progress whereby undeveloped or partly developed fields will be unit or near-unit operations.

In the Rocky Mountain region the Committee has endeavored to evaluate the savings in development and production costs. No effort has been made to estimate increased ultimate recoveries. It is our belief that in so far as the Rocky Mountain region is concerned unit operation should be justified through tangible savings rather than the uncertainties of additional barrels of oil. The interpretation of amount of increased ultimate recovery is often a subject of much controversy. Savings in well and production costs can not be disputed.

To evaluate savings in development and production through unit or near-unit operation, there should be a change from competitive to unit operation or vice versa during the life of the field; or at least the drilling of wells under unit operation should be complete. If these conditions do not exist, evaluation of the savings in drilling and production costs may be based on erroneous and unwarranted assumptions. The Committee has not felt justified in evaluating such savings in the near-unit operation fields, with the exception of Salt Creek.

Savings effected by unit operation for production and development costs alone are:

Rock River	$5,500,000	Rex Lake	$ 500,000
South Baxter Basin	1,716,000	Salt Creek	11,650,000
North Baxter Basin	272,000	Little Buffalo Basin	400,000
Hiawatha	714,000	Total	$20,752,000

These do not include such savings as reduction in general overhead, field and general office management, elimination of need for increased pipe lines and storage facilities, and gas plants to care for peak production, etc. These savings definitely prove that unit or near-unit operation is highly profitable whether or not there is an increase in ultimate recovery.

Without giving details, typical agreements applying to Rocky Mountain fields follow:

1. Full unit agreement wherein the owner is a single operator and the lessor a single royalty holder permitting a development and production program according to technical and not land requirements.

2. A field wherein one operator controls a large block in a field and the royalty interests have been consolidated.

3. Working agreements where one operator operates all or a large portion of a field under a contract, the contract reading that the operation is on a cost plus basis or that the operator pay a special contract price to the lessor for the crude.

4. Agreements to limit production to an agreed percentage of the potential or to shut it in altogether.

5. Agreements to limit drilling.

6. Agreements to share expenses in operation of gas drive projects.

7. Agreements in form of community leases whereby royalties are computed from production in large blocks comprised of a number of small leases.

Unit Operation Fields

Wyoming

Salt Creek.—There are 2131 oil wells; daily average production, 31,000 bbl.; operators, 31. It is estimated that the saving in wells and lifting cost amounts to $11,650,000. See detailed report.

Rock River.—Oil wells, 63; daily average production, 2100 bbl.; operators, 1; estimated saving in wells and lifting cost, $5,500,000. See detailed report.

Teapot.—Oil wells, 60; production, shut in; operators, 1; saving, not evaluated. Information not available.

South Baxter Basin.—Gas wells, 9; production, not available; operators, 2; estimated saving, $1,716, 000. See detailed report.

North Baxter Basin.—Gas wells, 2; production, not available; operators, 2; estimated saving, $272,000. See detailed report.

Hiawatha.—Gas wells, 6; production, not available; operators, 2; estimated saving, $714,000. See detailed report.

Rex Lake.—Oil wells, 4; daily average production, 80 bbl.; operators, 1; estimated saving, $500,000. See detailed report.

South Dome, South Casper Creek.—Oil wells, 29; daily average production, 1100 bbl.; operators, 1; saving, not evaluated. One company and one royalty holder are involved. The saving in this field has been primarily that of eliminating duplication of camps and management.

Boone Dome.—Gas wells, 5; production, not available; operators, 1; saving, not evaluated. Small gas-bearing structure operated by one company. This has not been evaluated because of its unimportance.

Hatfield.—Gas wells, 3; production, not available; operators, 1; saving, not evaluated. Small gas-bearing structure operated by one company. This has not been evaluated because of its unimportance.

Little Buffalo Basin.—Gas wells, 7; production, not available; operators, 3; estimated saving, $275,000. Operated as a unit. Production and royalties are computed using the percentage each owner's interest bears to total productive acreage.

Montana

Soap Creek.—Oil wells, 2; production, shut in; operators, 1; saving, not evaluated. Only two wells have been drilled on this structure. It is owned by one company and leased from one lessor. The saving cannot be intelligently evaluated at this time.

New Mexico

Hogback (by K. B. Nowels).—Oil wells, 7; daily average production, 500 bbl.; operators, 1; estimated saving, $80,000. This is a unit operation consisting of one

company and one lessor. Wells were drilled originally to explore productive area and far fewer wells have been drilled than would be necessary if the field had been competitively developed. Field is produced under back-pressure. Expulsive agent entirely water under pressure. Field may be shut in or opened at will.

Rattlesnake (by K. B. Nowels).—Oil wells, 13; daily average production, 1600 bbl.; operators, 1; saving, not evaluated. This is a field leased by the Government to one operator. It has not been competitively developed and appreciable saving has been effected in number of wells drilled. As recently a new sand has been proved productive it has not been considered advisable to evaluate saving in wells and production cost.

Table Mesa.—Oil wells, 6; daily average production, 110 bbl.; saving, not evaluated. This has been a one-company field and has not been completely developed. Until it has been fully drilled it is impossible to estimate saving in drilling and production costs.

Near-unit Operation Fields

Wyoming

Big Sand Draw.—Gas wells, 11; production, not available; operators, 1. This field is a unit operation developed after the field had been drilled. A large portion of the field was developed for drainage purposes although a few wells were drilled on account of competitive lease holdings.

Wertz.—Gas wells, 6; production, not available; operators, 1.

Mahoney.—Gas wells, 18; production, not available; operators, 4

Ferris.—Gas wells, 7 (production not available); oil wells, 12 (daily average production, 60 bbl.); operators, 1. The Wertz, Mahoney and Ferris fields are gas producers and are prorated into gas lines.

Billy Creek.—Wells, 7; production, shut in; operators, 1. Wells were drilled to protect different royalty interests but field was exploited largely according to geology. This is a gas field and has not been produced.

Golden Eagle.—Gas wells, 2; production, not available; operators, 1. One company has operated the gas wells in this field with a great saving in development cost.

Little Grass Creek.—Gas wells, 2; production, not available; operators, 1. This is a gas field with two gas wells which have been shut in awaiting a market.

Black Mountain (by John G. Bartram).—Oil wells, 6; production, shut in; operators, 1. One company operates this field, which is competitively owned but will not be developed by offset drilling.

Hudson.—Oil wells, 35; daily average production, 300 bbl.; operators, 1. Oil is produced as needed from this field and only necessary wells for drainage purposes have been drilled. The unit operation applies only to the Tensleep sand, the Embar formation being competitively operated.

Hidden Dome.—Gas wells, 6; production, not available; operators, 1. See detailed report.

Dallas-Derby.—Oil wells, 42; daily average production, 180 bbl.; operators, 1. Dallas is owned by a single operator and has been leased from one lessor, creating an ideal arrangement. Derby is not so fortunate in that the royalty interests are diversified.

Simpson Ridge.—Oil wells, 7; daily average production, 40 bbl.; operators, 1. This is a small field operated by one company.

Lost Soldier.—Oil wells, 74; daily average production, 3000 bbl.; operators, 4. There are four competitive operators in this field, one of which controls a large portion permitting a type of near-unit production program in the sands which have been competitively drilled. Lower horizons have been developed within recent years entirely within the acreage of the principal operator, which has made it possible to develop these newly found horizons according to unit programs.

Colorado

Wellington.—Oil wells, 22; daily average production, 1400 bbl.; operators, 1. One operator has developed and produced the field. This field has a free gas area on top and a ring of oil surrounding it. Only small amounts of gas have been taken from the top to satisfy royalty holders, thus making it of the near-unit type rather than the unit type. There has been a saving in drilling costs but the development has been largely competitive.

Fort Collins.—Oil wells, 15; daily average production, 350 bbl.; operators, 1. This field is operated by one company; although it has been leased from a number of lessors who have demanded competitive development, there has been a reduction in the number of wells required resulting from the one-company operation.

Tow Creek.—Oil wells, 14; daily average production, 450 bbl.; operators, 1. This field is operated by one company and consists largely of shale production. There has been a saving in the number of wells drilled over competitive operation but this saving is difficult to evaluate.

Moffatt.—Oil wells, 12; daily average production, 1000 bbl.; operators, 1. One company operates this field in its entirety. It has been drilled and produced with a saving, primarily due to the single management.

Montana

Bowes.—Gas wells, 7; production, not available; operators, 2. This is a gas field made up of large community blocks wherein the royalty holders have pooled their interests based on their respective acreage holdings.

Utah

Cisco (by C. M. Rath).—Gas wells, 10; production, not available; operators, 1. This is a gas field now operated by one company which has shown appreciable saving because of the small number of wells drilled.

New Mexico

Ute (by C. E. Dobbin).—Gas wells, 3; daily average production, 1,000,000 cu. ft.; operators, 1. This field is still undeveloped but in view of agreements now existing will undoubtedly be a unit type of operation.

Developed Fields Where There Are Cooperative Agreements

Wyoming

Mule Creek.—Oil wells, 42; daily average production, 500; operators, 3. Production is prorated as occasion demands. It is usually shut in during winter months on account of high cost of operation.

Big Muddy.—Oil wells, 171; daily average production, 2000 bbl.; operators, 4. Production has been prorated in the past. There are a number of agreements wherein land is operated on a cost-plus basis thus increasing the acreage under the supervision of one company.

Grass Creek.—Oil wells, 327; daily average production, 2000 bbl.; operators, 2. Two principal operators. Two horizons produce green and black oil. Green oil has been prorated and black oil now shut in awaiting market.

Maverick Springs.—Oil wells, 30; production, shut in; operators, 4. This field has been shut in for a number of years awaiting a market.

Elk Basin.—Oil wells, 145; daily average production, 700 bbl.; operators, 4. Three operators in this field have agreed upon a gas-drive program wherein the expense is prorated on the basis of the wells operated in the horizon receiving the benefit of injected gas.

Hamilton Dome.—Oil wells, 27; daily average production, 780 bbl.; operators, 3. Production is prorated in Hamilton dome depending upon the market.

Montana

Pondera.—Oil wells, 125; daily average production, 2500 bbl.; operators, 14. Production is prorated in Pondera depending upon the market.

Prospective Unit or Near-unit Operations

The following undeveloped or partly developed fields will be operated as unit or near-unit operations when negotiations are completed.

Wyoming:
- Enos Creek, proved for gas
- Midway
- Sunshine, oil
- Fourbear, oil

Idaho:
- Bald Mountain Dome

Montana:
- Mifflin
- Freedom
- Bears Den

Colorado:
- Fort Morgan
- Model, helium

Many of these fields have not been developed. In none of them are the productive limits known. Negotiations are in the making and hence details of the types of agreements are not available.

Unit Operation in Salt Creek Field

By Rocky Mountain A. I. M. E. Unitization Committee

This is a brief account of the history of unit operation in the Salt Creek field, Wyoming, from the time of the agreement to prorate production in March, 1921, to the present. An attempt has been made to evaluate the savings in development and production costs resulting from the unit plans adopted. Summarized, these savings have amounted to $11,650,000. No effort has been made to estimate any increase in ultimate recovery, for it is believed that unit operation can be justified on saving in development and production costs alone. It would require nearly 20,000,000 barrels of additional oil to be produced in order to return the amount saved by not drilling unnecessary wells.

Four horizons are affected by unit or near-unit programs, as follows:

Horizon	Productive Area in Acres	Discovery Date
First Wall Creek	3,320	1908
Second Wall Creek	20,000	1917
Lakota	2,000	1921
Third Sundance	500	1926

The principal operator is under contract with six companies to operate 10,400 acres. This includes all of the productive area of the First Wall

Creek, Lakota, and Third Sundance and a little over 50 per cent. of the area of the Second Wall Creek. Nearly 40 companies operate the remaining 9600 acres of the Second Wall Creek.

In the First Wall Creek sand, there have been four wells drilled to each 40 acres. This degree of development has shown economic drainage. If this sand had been developed under competitive operation more wells would have been required. As a result of the single company development, there has been a saving but it has not been evaluated in this report.

In 1921 there was insufficient pipe line capacity to market the potential production developed in the Salt Creek field. While the Lakota sand was known to contain oil, only the First and Second Wall Creek sands had been developed at that time. By mutual agreement the operators prorated the production. The outcome was the appointment, in September, 1922, of a conservation committee empowered to restrict drilling and prorate production. The membership of the committee was composed of selected representatives of operators in the field.

Only wells required to fulfill lease obligations were approved for completion and production by the conservation committee. At first the percentage of prorate was fixed at 65 per cent. As occasion demanded the wells were tested and a prorate percentage applied to satisfy current requirements. The prorates throughout the life of the conservation committee follow:

	Percentage of Potential Produced		Percentage of Potential Produced
Mar. 1, 1921	65	Nov. 13, 1922	40
Apr. 5, 1921	75	Jan. 1, 1923	20
May 25, 1921	60	Jan. 16, 1923	34
June 25, 1921	30–35	Aug. 25, 1923	65
Jan. 12, 1922	40	Nov. 1, 1923	34
July 12, 1922	30	Dec. 1, 1923	100

By Dec. 1, 1923, pipe lines had been laid with sufficient capacity to handle the production of the field therefore the committee was discontinued. There were 685 wells in the Second Wall Creek sand. Immediately after abandonment of the conservation committee all companies started drilling campaigns. During the following year nearly 500 wells were completed. These campaigns continued for nearly three years, until the total of 685 wells was increased to 1600 wells in the Second Wall Creek sand.

The policy adopted by the principal operating company was to offset all wells of other companies and to drill the inside acreage only in accord with the needs of drainage. The development of this company's

properties averages four wells to each 40 acres. As a result of competitive operation the other companies, with the exception of an area known to be barren of oil, have drilled an average of 5.5 wells per 40 acres. Four wells to each 40 acres have proved adequate to drain economically the sand of its oil.

Had the principal operating company been forced to drill the Second Wall Creek sand at the rate of 5.5 wells per 40 acres, 364 additional wells would have been required. These would have cost $5,460,000. If these wells had been drilled they would have been produced at an additional cost of $2,180,000. There was, therefore, a total saving of $7,640,000. Each lease in the Salt Creek field shows diversified royalty and working interests. These were necessarily protected. Had they been merged by some agreement the saving would have been even greater than shown.

In 1921 the discovery well was drilled into the Lakota sand. As the production was not needed the well was shut in pending the need for further development. The second well was drilled into the Lakota formation in 1924 and subsequent wells proved the productive acreage in this horizon to be within the properties operated by the largest operator. From previous experience it was known that the Lakota was highly porous and that even though the wells showed a large initial production (average 2000 bbl. per well) it would not be necessary to develop this horizon as intensively as other types of sands.

To make it possible to drill in accordance with drainage needs, royalties were purchased and efforts made to consolidate diversified interests. The result was that one well to every 22 acres has been drilled in this horizon. No oil was taken except for test purposes until most of the wells had been completed and this horizon was put on production as a unit. Excluding any consideration of increased ultimate production as a result of unit production, unit operation saved a total of 110 wells which would have been required had the area been owned by competitive interests. The saving in development cost amounted to $2,750,000. The saving in production cost will amount to $330,000.

Later development found oil in commercial quantities in what has been termed the Third Sundance. This, like the Lakota, was drilled to drain the sand properly and economically. One well per 22 acres will represent the development when the drilling program is completed. Like the Lakota, most of the wells in the Third Sundance were completed before any were produced, except for test purposes. The Third Sundance is flowing its production at this time under a high back-pressure and sufficient information has been developed to date to indicate that additional wells would be uneconomical. Under competitive operation it would have been necessary to drill at least 28 more wells. The saving resulting from unit operation has been 28 wells or $840,000 and a production cost of $90,000.

The above does not account for savings resulting from shutting oil in the ground when not needed, reduction in waste of gas by avoiding high peak production, elimination of need for costly storage and additional pipe line facilities, etc. The total saving of $11,650,000, therefore, is a minimum figure but it serves to justify unit operation from the viewpoint of the oil industry's pocketbook.

Unit Operation in the Rock River Field, Wyoming

With notes on the Rex Lake Field, Wyoming

By Wilson B. Emery,* Casper, Wyoming

The discovery well in the Rock River field, in Carbon County, Wyoming, came in May 1, 1918. The field is on a large anticline having more than 1500 ft. of closure and production is obtained from three sands of the Dakota group. At its peak, production approximated 10,000 bbl. daily and is now averaging 2200 bbl. Total production to Jan. 1, 1930, exceeded 12,500,000 barrels.

So far as known to the writer, Rock River was the first light oil field in the Rocky Mountain region to be produced under what we now term unit operation. Though this type of operation was not popularly acclaimed by the oil industry, the Federal Government and the public until many years after the inception of development at Rock River, the officials of the Ohio Oil Co. when acquiring this property were fully cognizant of the economies to be effected by unit ownership and the consequent elimination of competitive drilling and producing of wells, and had this in mind at the time. Thus unit management was introduced in this field at an early date by this company.

Area and Management

Fig. 1 shows the location of all wells drilled on the Rock River structure and the outline of the productive area as now defined, which amounts to 1380 acres. The hachured line indicates the area now under unit ownership; originally a much larger area was so owned but leases have been canceled as progressive development indicated their lack of oil.

The management and operation of the entire productive area is handled by the Ohio Oil Co., which owns the majority working interest. The Continental Oil Co. with a 20 to 35 per cent. interest in much of this acreage, and smaller interests owned by others in some of the leases, constitute the remainder of the ownership. The fee rests in the State of

* Geologist, Ohio Oil Co.

Wyoming and various individuals, except that one 40-acre tract is held under lease from the United States. Operation has been by individual leases but wells have been located as structure and production dictated.

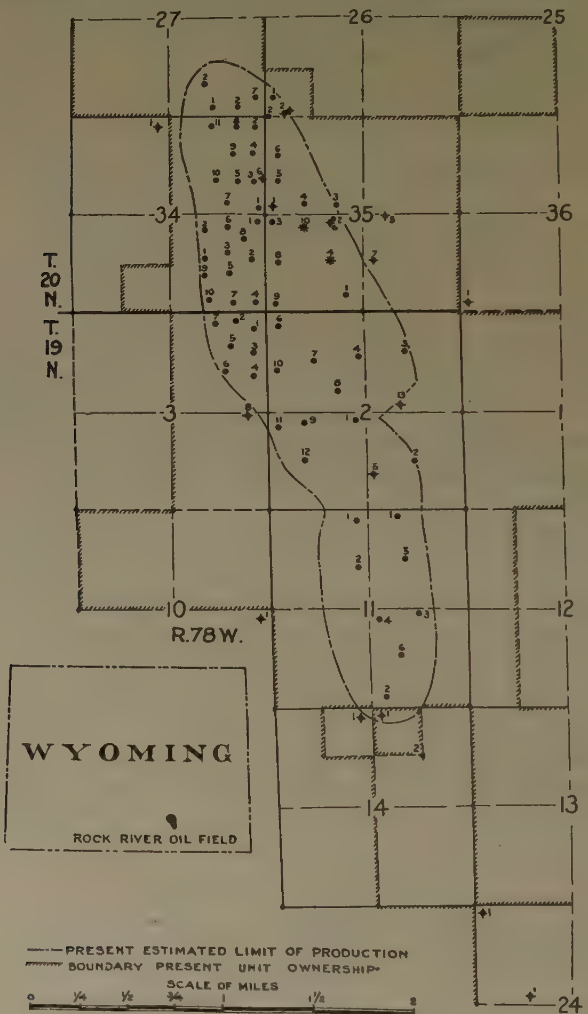

Fig. 1.—Rock River oil field.

Results of Unit Operation

General Statement.—So much has been said and written about unitization that it remains only to describe the results obtained by this type of operation. It is upon these results, interpreted as footings of the balance sheet, that unitization may be termed a business success or failure, and so an attempt has been made below to estimate the monetary saving of this

plan as used in the Rock River field. The problem therefore has been to approximate what the conditions and their accompanying expenses would have been under diverse ownership and operation. It is a somewhat more difficult problem than it would be to determine what economies might have been effected by unit operation of a field already developed and produced on a competitive basis.

The figures arrived at below are based on the fundamental assumption that the total gross production from this field would have been closely the same under competitive or unit operation. If the assumption is sound, and there is reason to believe it is, the figures indicate the order of magnitude of the saving accomplished, so far as the major expenses are concerned. So many factors, all interrelated, enter in the development and operation of an oil field that it is not practical, and probably not worth while in this case, to consider each item separately.

Drilling Expense.—As shown on Fig. 1, 83 holes have been drilled on the Rock River structure to date. Of these, 79 were drilled within the area of unit operation by the operating company; 68 were productive and 11 were dry. The three holes drilled outside of what was originally the unit-owned area failed to find production. A fourth hole encountered a showing of oil in the first sand but water in the deeper sands, and after two years of effort to shut off the water, is not yet a commercial well. This hole was drilled on a lease originally held by the Ohio Oil Co. but canceled when development showed the acreage to be so close to the water line that the company would be unwise to assume the hazard of drilling it.

Within what is now the proved productive area of the field, an average of one well has been drilled to each 20.3 acres. However, along the west flank, where the sands are more productive than elsewhere on the structure, wells have been more closely spaced and the average is one to each 10 acres (Fig. 1). Considering that this field was discovered at a time when close spacing of wells was common practice in oil fields, it seems probable that in the absence of unit ownership and operation the Rock River field would have witnessed an intensive drilling campaign and that wells would have been located at least as close together as on the west flank, where production has justified the drilling of one well to 10 acres. Thus we can reasonably estimate that some 138 wells would have been drilled. Beyond a doubt more dry holes would have been drilled in outlining the producing area, so that, everything considered, we can safely say that development by unit operation has cost approximately one-half of what it would have cost under competitive ownership. At an average cost of $50,000 per well the saving in drilling alone amounts to $3,500,000.

Certain items deserve individual mention. For example, no doubt there has been an intangible but nevertheless important saving in the orderly drilling of the field with crews familiar with the formations

from long experience, a saving that would have been absent in rapid development under diverse operation. Further, the steepness of the structure and the cavey character of the formation made drilling difficult and necessitated long strings of pipe, a hazardous operation with the light-weight pipe used in Wyoming at the time this field was discovered. It is not to be supposed that a considerable saving was not effected by the Ohio Oil Co. through the introduction of heavier pipe and the consequent reduction in expensive fishing jobs attendant upon the use of the lighter casing. True it is that the monetary value of this saving cannot be even roughly calculated, but there can be no doubt that it was a sizable sum, for under competitive development many more holes would have been drilled before the use of heavy casing became common practice. Also, there has doubtless been a further intangible saving in unit operation by a major company that would have been lacking had any of the productive acreage been developed by inexperienced promotion companies on a competitive basis, or by companies unfamiliar with Wyoming conditions. Overhead and general expense chargeable to drilling must also be less under unit operation. All these savings are reflected in the cost of the average well as given above.

Oil Expense.—In this section oil expense is used to cover costs directly incident to the actual bringing of the oil to the surface; *i. e.*, lifting expense and such items of non-lifting expense as costs of dismantling wells and surface equipment. It does not include depreciation and depletion of wells and farms, and intangible development costs which must be paid out of production but are not expenses entailed in the physical production of oil. General and camp expense as well as taxes for which production must pay are discussed under another heading.

Under lifting expense are included the wages of foremen and pumpers, constituting about 30 per cent. of the total cost in the Rock River field; repairs to wells, 25 per cent.; surface equipment including material, 22 per cent.; cleaning out wells, 10 per cent.; and fuel, water, incidental supplies, and other items, 13 per cent. An increase in the number of wells operated to recover an equal volume of oil will proportionately increase some of these items while others will be affected to a smaller extent. For example, if it is substantially correct to think that competitive operation would have resulted in drilling twice the number of wells that were drilled under unit operation in the Rock River field it is fair to assume that the item of surface equipment in the lifting charge would be doubled, for in this field all wells are pumped with individual equipment. Similarly, it is to be expected that repairs to wells and cleaning out would be largely increased, though perhaps not doubled. Depending upon the diversity of ownership the number of foremen would be increased several fold but the number of pumpers would not be so greatly augmented, for with more wells pulling on the same amount of

oil they would pump off sooner and one pumper could look after a greater number. Perhaps 70 per cent. is a fair estimate of the increase of lifting expense that would have accompanied competitive operation in this field. This would amount to something over $2,000,000 during the life of the field.

Abandonment of wells and surface equipment is the principal item in non-lifting expense, and this expense would increase in direct proportion to the number of wells. It is estimated that the average cost of abandoning a well in the Rock River field will not run under $1200, and if it is correct to assume that some 70 additional wells would have been drilled in the productive area under competitive operation, then the added cost of abandonment would be not less than $84,000. It might run as high as $100,000. Loss and damages would no doubt be larger with more wells and more operators but they are by their very nature so variable that it is not advisable even to hazard a guess as to their amount.

Some difference in oil expense and return would have occurred had the field been rapidly developed under competitive operation, because a larger amount of flush production would have been marketed at the high price of oil obtaining in the early life of this pool, a price that has not been witnessed since. As there has always been an adequate market for this production, price has been influenced by the general condition of the oil business rather than by the local situation. Therefore it was probably fortunate that this pool was unit-operated during the depression of 1921 when the price declined to 60c. per bbl., for production was curtailed, obviating the necessity of either producing to capacity and sacrificing the oil or building storage for use pending an increase in price. This feature alone may have approximately balanced any gain that would have resulted from a larger flush production under competitive development. It might be suggested that a larger flush production would have returned the investment faster, thereby reducing interest charges, but it must not be forgotten that to have obtained a larger production more wells would have been necessary and interest charges would have increased in proportion to the investment.

Oil expense has no doubt been held down by the conservation of gas in the sands, accomplished by shutting in wells on top of the structure when the gas-oil ratio becomes excessive, and by returning to the sands dry gas that has passed through the gasoline plant. With varied ownership and operation and its attendant rush to reduce oil to possession regardless of the dissipation of gas, which because of its propulsive force is the most valuable asset in the production of oil, there would have been little incentive to conserve gas and oil expense would have increased more rapidly than with unit operation.

Other Expense.—Other large items of expense are general expense, camp expense and taxes. Under the Wyoming laws casing in wells is

not assessed but oil produced is assessed as personal property, which is in effect a production tax and constitutes the bulk of oil-field taxes. As it is anticipated that the amount of oil produced would be approximately the same under unit or competitive operation, the variation in taxes would not be large and may be disregarded in the present consideration.

On the other hand, competitive operation would greatly increase general and camp expense, necessitating, as it would, separate management, office and field forces, and camps for each operating unit. The loss from such duplication and the consequent decrease in efficiency is not susceptible of precise calculation, but over the life of the field it would run into sizable figures. Perhaps an estimate of $500,000 may approach in magnitude the actual saving in these expenses through unit operation.

Intangible Benefits.—Certain intangible benefits of unit operation are reflected in the figures given for drilling, production and other expenses and it is perhaps desirable to point them out since otherwise they might escape attention. Probably the most important is the permanent nature of the camps, which permits better living conditions for the men and their families than is possible where camps are temporary. The men know that so long as business conditions warrant and their work is satisfactory they may have these advantages for themselves and families and consequently there is a reduction in labor turnover that in the long run must result in important savings through the retention of efficient employees over extensive periods. Of the total number of men on the field payroll for the first half of January, 1930, 84.7 per cent. had been in the continuous employ of the Ohio Oil Co. either in the Rock River field or elsewhere for three years or longer; 65.4 per cent. for five years or longer, and 21.8 per cent. for ten years or longer.

Another intangible result of unit operation is the greater discounts obtained through large-scale purchases of supplies and materials for a whole field as compared with only the customary discounts for cash where supplies are bought in smaller quantities for a single lease. Over the life of the field a considerable saving will result from this item alone, and be reflected in the balance sheet.

Rex Lake Field

The Rex Lake field in Albany County, Wyoming, was discovered in 1923. It has an estimated producing area of 320 acres, all of which is leased and operated by the Ohio Oil Co. Four producing wells have been drilled and production obtained from the sands of the Dakota group, as at Rock River. There has also been drilled one shallow gas well and a dry hole, the latter outside the area of unit ownership. It is doubtful if any other drilling within the productive area is now warranted.

None of the wells in this pool ever flowed their production, but in its early history it was impossible to pump the wells off.

Wells in this field average about $85,000 each in cost. Competitive operation might have resulted in four or five more holes drilled and it is therefore safe to estimate that between $350,000 and $400,000 has been saved through unit ownership and development of this property. The saving in oil expense, general and camp expense, taxes, etc., over the life of the field is estimated at $100,000. An outstanding beneficial result of unit operation at Rex Lake has been the ability to produce the field exactly in accord with market requirements.

Summary

Unit operation in the Rock River field has resulted in economies running into millions of dollars in value. Drilling cost would have been approximately 100 per cent. more and producing expense over the life of the field 70 per cent. more than it would have been under unit operation while general and camp expense would have been increased perhaps one-third. Orderly development, balancing production with market requirements during the period of flush production, conservation of gas and utilization of excess gas for repressuring are other noteworthy benefits of unit operation in this field. It is probably safe to state that $6,000,000 will have been saved in the development and operation of the Rock River field over its life by this type of operation.

At Rex Lake the saving through unit operation is estimated at close to $500,000.

Unit Operation as Proposed for the Hiawatha, South Baxter Basin and North Baxter Basin Gas Fields in Southwest Wyoming and Northwest Colorado

By William T. Nightingale,* Rock Springs, Wyoming

The three gas-producing "pools" discussed in this paper are in Sweetwater County, southwest Wyoming, and Moffat County, northwest Colorado. Hiawatha, North Baxter Basin and South Baxter Basin gas fields became economically important in 1929 when a 330-mile gas line connected them with Salt Lake City, Ogden and towns en route. This development immediately focussed attention on the gas-producing fields and the efforts of the producing company to develop them in an orderly, economical manner. Several outstanding interests were acquired and working agreements made with others. Thus the interference of natural drainage areas was avoided, the pernicious practice of drilling direct

* Chief Geologist, Mountain Fuel Supply Co.

offset wells largely stopped and gas wastage in every form became more thoroughly controlled.

Hiawatha Dome

Geology.—Hiawatha dome, the field terminus of a gas line to Salt Lake City, is a gently folded and unfaulted dome with some 235 ft. of closure. The surface rocks and also the rocks of the producing horizons are fresh-water shales and sandstones (Eocene age) with several included coal beds.

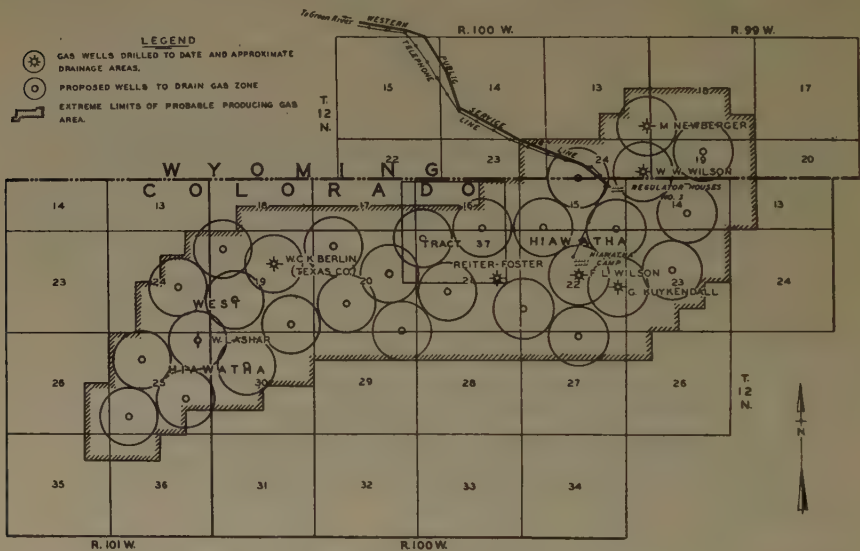

Fig. 2.—Unitization drilling plan proposed for Hiawatha gas pool, Moffat County, Colo., and Sweetwater County, Wyo.

Development.—The first gas well was drilled in 1926–1927 and made 50,000,000 cu. ft. at 2215 ft. Several later wells were also large and two highly productive gas sands were developed. Another gas sand was found at 3550 ft. but the one well penetrating it made only 3,250,000 cubic feet.

West Hiawatha

Two miles west of Hiawatha dome and about 125 ft. structurally down its west flank is a secondary dome with some 57 ft. of closure. A well drilled during 1929 found two big gas sands and two small gas sands at intervals from 1535 to 2245 ft., which yielded a combined flow of approximately 65,000,000 cu. ft. per day.

Unitization.—At present all of the probable gas-producing acreage in the Hiawatha-West Hiawatha gas area is held by either the Mountain Fuel Supply Co. or the Texas Co., the former holding some 70 per

cent. and the latter, 30 per cent. Since most of the acreage is held under permit or lease from the United States Government, the attitude of Department of the Interior is particularly interesting. In granting an extension of two years, dated Oct. 2, 1929, on permits at Hiawatha and in adjacent areas where group development is planned, the following condition was included:

It is further recommended that in order to obtain beneficial use without waste of any and all gas developed, each extension of time allowed be with notice that a concerted effort must be made by each permitee within the period of extension looking to the development of a conservation program for the operation of the particular area wherein the permitted lands are located, such a program to be subject to approval by the Department.

As in the final analysis the greatest degree of conservation of oil or gas is made possible by unit operation, the condition promulgated by the Department of the Interior would appear to be a direct endorsement of a unit operation program.

In Fig. 2, the area in a unit operation program, as proposed for the Hiawatha-West Hiawatha area, is outlined and the various wells drilled to date are shown. During the summer of 1929 a carefully prepared geological map of the gas area was constructed. This map, together with the logs of all wells drilled to date, indicates that Hiawatha and West Hiawatha are so connected structurally that any economical operating program, to be really successful, must treat the two gas areas as a single unit because of the extreme shallowness of the syncline between them. In later pages, therefore, "Hiawatha" will be used to include both Hiawatha dome and West Hiawatha dome.

The greatest financial saving to be made in a unit operation program at Hiawatha is through the elimination of unnecessary drilling. This requires that careful attention be given to well spacing. The nature of the producing sands, their tendency toward lenticularity, the extreme variability in porosities and size of sand grains from place to place, all tend to make the problem of efficient spacing uncertain. At present well spacing is in the experimental stage and two or three years of drilling, producing and data recording will be necessary before well-founded conclusions can be reached. However, a tentative plan of drilling has been drawn up, based on general Rocky Mountain practice, which is believed to be reasonable and conservative despite the lack of required experimental data. In Fig. 2, this tentative drilling plan is outlined.

Fig. 2 shows the limits of the pool as now interpreted. This area includes 11 United States Government oil and gas permits and one tract of state-owned land. In the proposed drilling plan approximately 160 to 180 acres are allowed, arbitrarily, for complete drainage to each proposed gas well. The plan requires 26 wells for any single sand or sand zone extending over the structure. Compared with this, a drilling program

in which the different permit holdings are protected by regular offset wells and inside locations drilled at the rate of one well to approximately each 160 acres would require not less than 50 wells to accomplish similar drainage.

It is, of course, probable that unknown edge field conditions may cause some changes in any complete drilling program proposed. Furthermore, subsurface information on lenticular producing sands at Hiawatha may also require changes. Any proposed drilling plan must remain flexible for these reasons.

Based on past experience, wells are expected to cost about $30,000 each. Therefore, we have the following: 50 wells at $30,000 per well in ordinary drilling plan, $1,500,000; 29 wells at $30,000 per well in unit operation drilling plan, $870,000; estimated saving through unit operation $630,000. A further saving in metering cost and equipment is estimated at $4000 per well, or $84,000, in addition to which a considerable charge for additional gathering lines is saved. Compared with divided ownership there is also a large saving in overhead charges.

A comparison of the ultimate production under a unit operation plan as against an ordinary drilling program in a gas field such as Hiawatha is difficult to make. With the only market outlet from Hiawatha through the pipe line of the Western Public Service Corpn., that company would necessarily have been obliged, under any development program, to prorate the market consumption between the total number of producing wells. As the amount of gas taken from any well would have been a comparatively small proportion of the total capacity of the well, and therefore in accordance with good gas-production practice, it is doubtful whether the ultimate gas production would be materially different under any drilling plan that would exhaust the gas sands over a considerable period of time. This is especially true in that inside as well as offset locations would of necessity be drilled under any drilling program. Of course, any production plan that would allow the control and regulation of encroaching edge water is desirable, but no data are available on this phase of production at Hiawatha as yet.

The drilling, blowing and testing of any high-pressure gas well uses up a considerable amount of gas. It is estimated that, at Hiawatha, up to 25,000,000 cu. ft. may easily be wasted on each well in these operations. By reducing the number of drilling wells this waste can be proportionately lowered.

South Baxter Basin

South Baxter Basin gas field, in Sweetwater County, Wyoming, is also on the Salt Lake gas line.

Geology.—South Baxter Basin gas field occupies the structural crest of the Rock Springs uplift, which extends some 85 miles in a general

north-south direction, and brings Cretaceous rocks to the surface over an area of 100 sq. miles. These are surrounded by Tertiary beds.

Although the broad structure is essentially a dome, it is so cut and displaced by faults that the structural conditions affecting gas accumulation and retention are very complicated. Further complications result from an extensive remnant of unconformable Tertiary (Miocene?) sediments that tend to obscure the fault structures.

Production at South Baxter Basin is from two horizons, the Frontier sandstone and the Dakota sandstone, both of Cretaceous age. In general the Dakota sand wells are much larger than those from the Frontier sand horizon.

Development.—As early as 1900 random drilling found sufficient "shows" of oil and gas to continue interest in the region.

In 1922, the Ohio Oil Co. drilled the first big gas well in the faulted area on the south end of the dome. This well made 36,000,000 cu. ft. from the Dakota sandstone at a depth of 2475 ft. This was followed (1922–1929) by several large gas wells drilled by several companies. At present there are 10 wells with a combined open flow capacity of 288,000,000 cubic feet.

At present the acreage within the probable producing gas area is held for development purposes as follows: Mountain Fuel Supply Co., 69.1 per cent.; other interests, 30.9 per cent. The acreage held for operation by the Mountain Fuel Supply Co. and other interests is classified as follows: U. S. Government permit and lease acreage, 39.8 per cent.; Union Pacific R. R. lands under lease, 52.1 per cent.; State of Wyoming land under lease, 6.6 per cent.; patented land under lease, 1.5 per cent. Fig. 3 shows the area considered as probable gas territory and also the various wells completed or drilling at the present time.

Unitization.—Fig. 3 is based on a rather free interpretation of the geology. The irregularities are due to slice faulting and resultant displacements. As pointed out under the Hiawatha discussion, the greatest saving to be made through unit operation is in the elimination of unnecessary drilling. Fig. 3 illustrates the proposed drilling program and shows the required wells and the approximate drainage area allowed to each location. Gas wells already drilled under the old "acreage protection" plan are also indicated. In almost every case the gas wells already drilled conflict in their natural drainage areas.

Under the "acreage protection" plan it is estimated that a minimum of 90 wells would be required to protect the different acreage holdings and secure reasonable gas drainage throughout the area. Under the proposed unit operation plan a total of 51 wells will suffice to produce at least an equal amount of gas. The average cost per well is about $40,000: 90 wells at $40,000 per well in ordinary drilling plan, $3,600,000; 51 wells at $40,000 per well in unit operation drilling plan, $2,040,000;

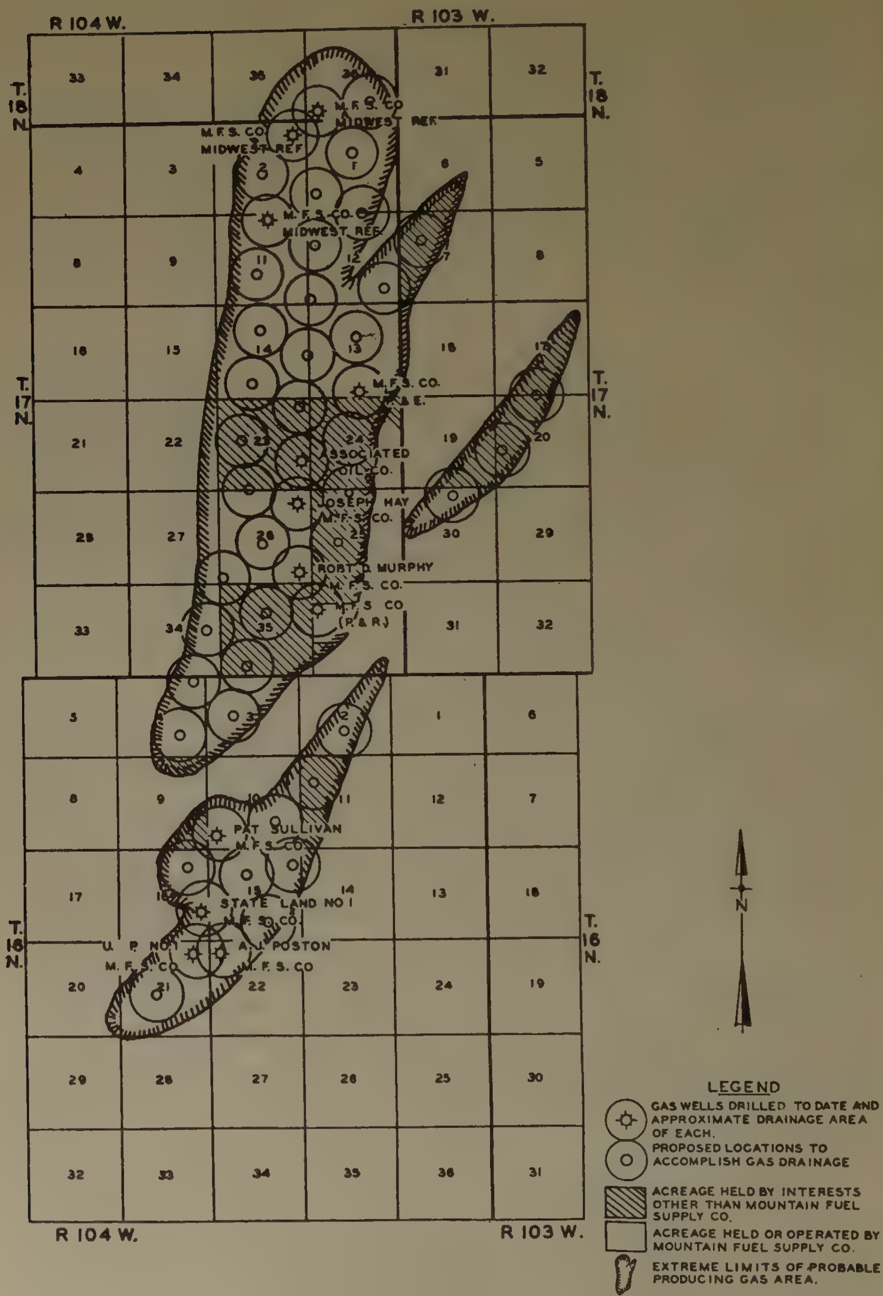

FIG. 3.—UNITIZATION DRILLING PLAN PROPOSED FOR SOUTH BAXTER BASIN GAS POOL, SWEETWATER COUNTY, WYOMING.

saving through unit operation, $1,560,000. In addition a considerable saving on meter equipment costs is effected. At $4000 per well for meters, meter building, fittings, etc., we have: 90 wells with meter equipment under "acreage protection" drilling, $360,000; 51 wells with meter equipment under unit operation drilling, $204,000; saving through unit operation, $156,000. On the two items of drilling costs and meter equipment costs alone, it can be demonstrated that a total saving of $1,716,000 may be effected at South Baxter Basin by unit operation. In addition a large saving in gathering lines is effected.

Faulting at South Baxter Basin, especially in the southern part, has complicated subsurface conditions. Until more drilling is completed and the effect of faulting on the production is more throughly determined, any proposed unit drilling plan must be kept flexible and subject to necessary changes. Fig. 3 must be considered in the light of a preliminary plan only in so far as spacing is concerned.

The same conditions apply to production costs and total ultimate gas production at South Baxter Basin as were discussed under Hiawatha.

North Baxter Basin

North Baxter Basin gas field is in the northern part of the Rock Springs uplift. The Western Public Service Corpn. has constructed an 8-in. branch gas line from the Hiawatha-South Baxter Basin-Salt Lake City main line to the North Baxter Basin gas field, thereby creating a market for gas from this field.

Geology.—North Baxter Basin gas field is structurally a dome superimposed on the major Rock Springs uplift but is structurally 1300 ft. lower than South Baxter, 8 miles away. A system of northeast-southwest trending normal faults complicates the problem of gas accumulation and retention. Three horizons produce gas, namely, Frontier and Dakota of Cretaceous age and Sundance of Jurassic age.

Development.—The first commercial gas well was drilled in 1926 and made 10,000,000 cu. ft. from the Frontier formation and 14,000,000 cu. ft. from the Dakota formation. A second gas well drilled on the south end of the dome yielded only a show in the Frontier and Dakota horizons but made 3,800,000 cu. ft. from the Sundance formation. It appears probable, from the results obtained in this well, that the Sundance formation has a much greater area for gas production than either the Dakota or Frontier formations.

The Mountain Fuel Supply Co., when organized, acquired by purchase the Ohio Oil Co. acreage at North Baxter Basin and also the gas rights on the Producers & Refiners Corpn. and the Marland Oil Co. acreage. Thus at the present time the probable gas acreage at North Baxter Basin is held as follows: Mountain Fuel Supply Co., 97.1 per cent.; other interests, 2.9 per cent. This acreage may be classified as follows:

U. S. Government land under permit or lease, 46.7 per cent.; State of Wyoming land under lease, 1.3 per cent.; Union Pacific R. R. land under lease, 52 per cent.

Unitization.—Fig. 4 outlines in a general way what is believed to be a reasonable idea of the gas-production limits at North Baxter Basin and illustrates a proposed general plan showing the required locations

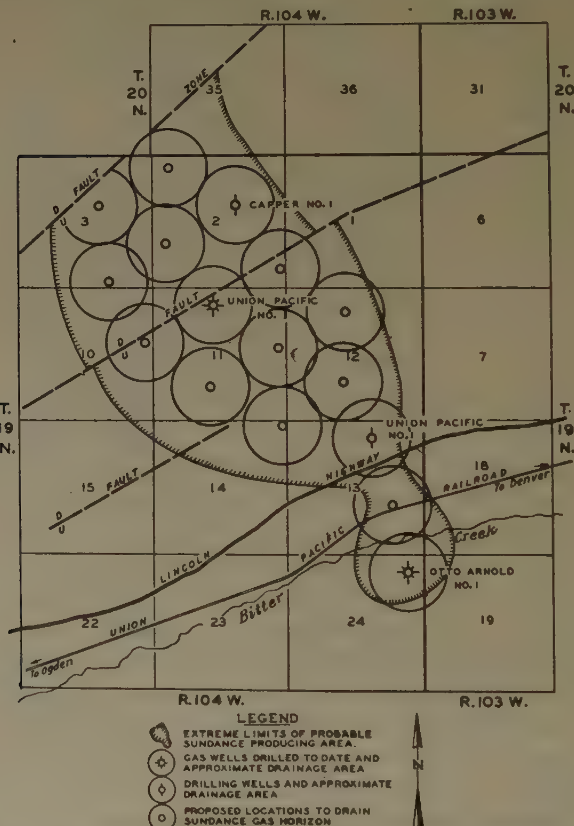

Fig. 4.—Unitization drilling plan proposed for North Baxter gas pool, Sweetwater County, Wyoming.

and the drainage area allotted to each well. This plan allows for 16 wells to secure economical gas drainage. Any "acreage protection" plan of drilling would require a minimum of 24 wells to secure drainage of the same area.

At North Baxter Basin it is estimated that a gas well will cost $30,000 to complete: 24 wells at $30,000 per well in ordinary drilling plan, $720,-000; 16 wells at $30,000 per well in unit operation drilling plan, $480,000; saving through unit operation, $240,000. In addition, the elimination

of eight unnecessary wells permits a saving of $32,000 on gas-metering equipment.

The proposed plan is subject to change based on subsurface conditions as found in the next few wells drilled.

CONCLUSIONS

In the opinion of the writer, the greatest inducement for unitization in the three gas "pools" tributary to the Salt Lake City gas line of the Western Public Service Corpn. is in the greatly decreased investment necessary to develop the properties. Next in importance is the reduced cost of operation due primarily to the decrease in the number of independent operating establishments in the different fields. It should be noted that in a producing gas field the operating personnel does not by any means increase proportionately as the number of wells on production and operated by any one company. In fact, the several operating gas companies in one pool would largely duplicate the staff required by a single operator.

Finally, as to ultimate production, it appears that the same total amount of gas may be expected in the fields herein treated by approximate unitization as in an "acreage protection" drilling program. Some advantage should undoubtedly be obtained by unitization through more thorough control of edge wells and edge-water encroachment but no data are yet available on this phase in the fields considered, because so few wells have been drilled and the fields have been on production for so short a time.

The gas line of the Western Public Service Corpn. is the only outlet for gas in the Hiawatha and North Baxter Basin gas fields and the major outlet for gas at South Baxter Basin. As a result, the gas operations of the fields are on a prorate rather than a competitive basis. Only a small part of the total capacity of the 18 producing gas wells in the three fields at present can be taken on a prorate basis by the pipe line. As more gas wells are drilled this acceptance proportion per well must become less. This situation, in its effect, necessitates economical production methods and a gradual depletion of the producing sands over the gas area. This, so far as we now know, assures a satisfactory ultimate recovery and considerable control over edge conditions under any drilling program.

However, with waste controlled, ultimate production at least as great, production costs lowered and well investment greatly reduced, unitization appears highly justifiable both on the basis of economy and conservation.

Unit Operation in Hidden Dome Gas Field, Wyoming

By Wilson B. Emery,* Casper, Wyoming

The Hidden Dome gas field, situated in Washakie County, Wyoming, was discovered Sept. 26, 1917. Subsequently five additional gas wells were completed and a large reserve was developed. For a number of years this field completely supplied the domestic market at Basin and Greybull, as well as the refinery at the latter town, and it is still supplying gas in small amounts to this market.

Production is obtained from the sands of the Frontier formation at depths ranging from 1000 to 1500 ft. The original rock pressure was 725 lb. and initial production ranged from 4,000,000 to 28,000,000 cu. ft. per day per well. Porosity of the sand, determined from the size of the productive area and the amount of gas recovered, is over 18 per cent.

Area and Management

It is estimated that the productive area is about 640 acres. Its outline is indicated on Fig. 5, on which are also shown the locations of holes drilled on the structure and the area of unit operation.

The unit area is owned by the Ohio Oil Co. and development and operation have been by this company. No productive well has been completed outside this area. The entire area was Government land filed on under the placer mining law.

Results of Unit Operation

With six producing wells, or an average of one to each 160 acres, the pool is completely developed. Location of the wells was made with respect to structural conditions plus the requirement that at least one well be drilled on each 160-acre placer claim. Perhaps a somewhat more uniform spacing of the wells might have been accomplished and one well eliminated, but it must be borne in mind that the holes, on account of their shallow depth, were not expensive and that the object was to develop as reliable a reserve as possible. There is no cause to suspect that these holes have not adequately drained the reservoir and there is every reason to think that any additional wells, which might have been drilled under diversified ownership and operation, would have been an economic waste.

Unit operation by a competent company has not only resulted in the elimination of loss of gas through careless development and operation

* Geologist, The Ohio Oil Co.

but has conserved the product for its best use, as fuel for domestic purposes and for industry. It is possible that without unit ownership and management the gas might have been burned for carbon black or dissipated in other ways, for when the field was discovered the time was not ripe for the construction of a pipe line to reach the market ultimately

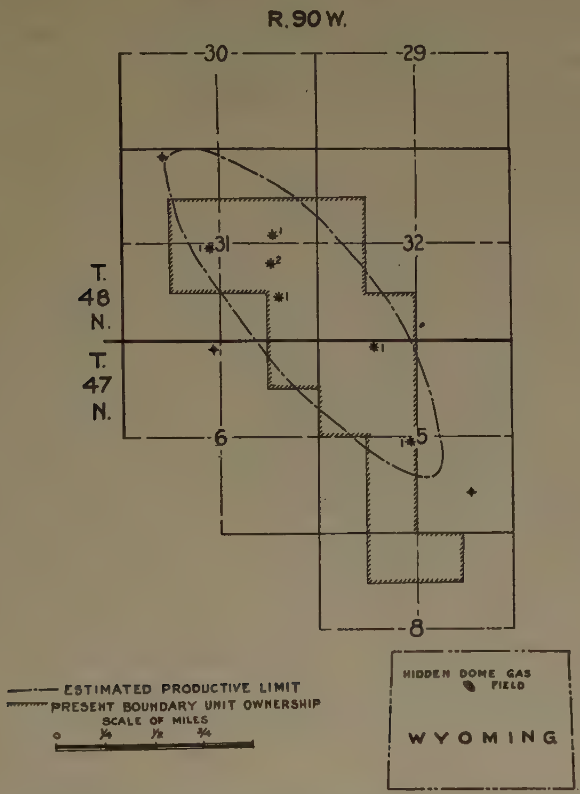

Fig. 5.—Hidden Dome gas field, Washakie County, Wyoming. Hachured lines indicate boundary of area of unit operation.

served. In at least one competitively operated field in Wyoming this has occurred, and perhaps the prevention of this has been the most outstanding and beneficial result of unit operation at Hidden Dome.

Turning from what may be considered the more or less altruistic phase of unit management in this pool, there can be no doubt that a concrete, though not precisely determinable, dollars and cents saving has been accomplished in general expense and camp expense as well as in development expense by this type of operation. Fewer repairs to wells have been necessary than with the larger number that would probably have been drilled without unit operation, and only part of one man's time has

been required to look after the property, as compared with perhaps the full time of several men under varied ownership.

Summary

It may be said that investment and expense in the Hidden Dome gas field have been held down to a minimum by unit operation, and the gas conserved and used for its most beneficial purpose, as fuel. It is doubtful whether these results would have been even closely approached under diversified ownership and management.

Unit Operation in California*

By Joseph Jensen,† Los Angeles, Calif.

(New York Meeting, February, 1930)

No outstanding example of an important producing unit operation exists in California today where the competitive drilling drainage feature is or was entirely eliminated We need not feel, however, that the thought of unit operation had its birth in 1924, when Henry L. Doherty named and sponsored it so strongly before the American Petroleum Institute and our own organization. No man or company in California ever drilled a wildcat well without exerting every possible effort to get all of the structure, so as to control drilling and avoid competition. Overproduction did not begin in 1923, so there has always been the wish to avoid it. In this state the practice of selling acreage around a wildcat has not been followed, except possibly in rare instances. The operator drilling the wildcat knew he must pay the bill alone, so he endeavored to get the benefit of his effort by tying up all of the land around his well and by so planning his different lease obligations as to avoid as much offsetting as possible. If he failed to get all of the land, it was because someone's price was too high, some other oil man also had the same idea and already held some lands, a competitor took leases away from him while his work was still incomplete, or (as was so often the case) the hidden structure when developed did not prove to be where the wildcatter thought it would be. The last named condition often led to a forced drilling campaign by the last leases secured and thus to serious drilling drainage problems.

Ownership of the Land

The land situation differs a great deal in various parts of the state. In the San Joaquin Valley, all the land is surveyed into sections and townships. Railroad land grants embraced a part of the land. In the areas that were developed at an early date, as at Kern River, Coalinga, McKittrick and the Sunset-Midway field, such land as the railroad company's diligent land department had been unable to sell for a song as grazing land still remained in its ownership. Operation and ownership

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* Published by permission of J. H. Jenkins, General Manager of the Production Division, Associated Oil Co., San Francisco, Calif.

† Chief Petroleum Engineer, Associated Oil Co.

of this retained railroad land passed from the Southern Pacific Co. to the Pacific Oil Co. in 1921 and to the Standard Oil Co. in 1926.

Strange as it seems to many of us now who cross the arid western side of this great valley, numerous colonization schemes in the seventies and eighties were attempted in this barren district. San Francisco bankers took advantage of the low prices of greenbacks, using them to buy big blocks of Government land during this period. Thus it was that the Belridge Oil Co. was able to purchase from the owners of such almost useless land 36 sq. miles of contiguous land on which it later found two oil fields. Even so, it did not succeed in getting all of these two fields.

The very hilly land, however, was left untouched. Title to this still remained in the Government or the railroad where the land grant extended out to the hills. Tracts of 160 acres were taken up as placer mining claims by nearly every resident in the country—just paper claims, but thousands of them overlapping and repeating so often that the office of County Recorder became one of the best paying in the state. Only two instances exist where enough contiguous placer mining locations were held in one ownership ultimately to give a large tract of well-controlled and well-located acreage on important structures. One of these is represented by the property of the Honolulu Consolidated Oil Co. in the Buena Vista Hills, Sunset-Midway field; the other is the Texas Co's. holdings in the Oakridge or South Mountain field in Ventura County.

Prior to 1900, the practice of developing this San Joaquin land was to acquire full title to it by purchase or by placer mining location. This and 15 to 25-c. oil limited the amount of land taken up by each ownership. The industry was not well established and there were therefore many operators drilling shallow wells. Many ownerships and the need of reduced operating costs were responsible for consolidations that resulted in forming some of the companies that have since become the major operators in the state. This was particularly true in the Kern River field. Relatively few leases existed. Because of such conditions and the subsequent consolidations, it has been possible to shut in most of the 99,303 bbl. of oil in this general area. This practice of purchasing lands was followed to a large degree by the Union Oil Co. during this same period in other parts of the state, and with like results.

Along the coast there were immense old Spanish land grants. In Ventura and Santa Barbara counties, particularly, these have not yet been cut into small tracts, as they generally have been in the Los Angeles Basin. This condition accounts for such fields as Lompoc, Santa Maria, Elwood, Ventura and Tapo Canyon.

Selling real estate has been the prime Los Angeles industry as far back as the memory of the oldest among us runs—and some there are who would have everyone understand that Los Angeles means all of Southern California. Hence, in this general area, where some large

parcels of land still exist, there are many districts of 5 to 25-acre parcels with near-by town-lot subdivisions. This town-lot condition occurs in such fields as Signal Hill, Santa Fe Springs, Huntington Beach and Alamitos Heights; while in the same district are such fields as Dominguez, Main Seal Beach, East and West Coyote, Montebello, Inglewood and Beverly Hills, with one to five operating companies in each field. In addition, this district gives a combination type of land ownership, represented by Brea-Olinda, Salt Lake, Whittier and Richfield.

Near-unit Operation

The more people it became necessary to deal with, the more difficult the opportunity for securing a single control, but the urge for single control was always present. What has thus far been accomplished may best be classed as near-unit operation. It represents a commendable record of achievement. Until 1929 it bore the entire burden of curtailment and controlled development in California. There is still possible in these near-unit fields controlled deeper drilling in some and in all an excellent opportunity for gas storage and repressuring work to increase oil recovery. Fields falling in this class, assembled according to the geographic districts in which they occur, are shown in Table 1.

TABLE 1.—*Fields from Which Production May Be Expected*

	Daily Average Production During Peak Year, Bbl.	Daily Average Production During 1929, Bbl.	Average Number Producing Wells During Peak Year	Number Producing Wells, February, 1930
San Joaquin Valley				
Belridge*	(1917)			
Fruitvale	1,629 (1929)	1,629	6	11
Round Mountain	613 (1929)	613	5	12
Wheeler Ridge	1,019 (1926)	685	25	33
Coastal				
Santa Maria-Lompoc	23,769 (1908)	4,208		209
South Mountain*	(1925)			176
Shields Canyon	1,336 (1916)	539	109	101
Ventura Avenue	57,354 (1929)	57,354	154	140
Tapo Canyon	328 (1919)	161	24	39
Los Angeles Basin				
Wolfskill Dome*	(1911)			
Inglewood	52,136 (1925)	24,022	171	228
Potrero (South Dome)	611 (1929)	589	3	3
Dominguez	36,848 (1925)	9,882	62	57
Seal Beach Main Field	35,334 (1929)	35,334	69	77
Montebello	30,153 (1919)	11,567	118	176
Coyote (East and West)	34,286 (1918)	11,441	183	208

* Data on these fields have been included with others and can not be separated readily.

There is one marked difference in the California oil fields as contrasted with the usual conception of oil fields elsewhere. This difference may be expressed in one of two ways: Either there was insufficient gas to make an accumulation of gas on top of the structure free from oil, or the accumulation of oil on the crest of the structure was sufficiently great to furnish oil to hold most of the gas in solution. While it must be true that the gas-oil ratio on the very crest of the structure is different from that down the dip, this difference is not always pronounced. A much greater difference occurs in wells based upon the length of time in which they have been producing. The effect of the age of a well upon the gas-oil ratio is much more pronounced than is the effect of structural location. Such a condition limits the extent to which unit operation might help in the development of a field by eliminating drilling on top of the structure. On the other hand, control of the producing wells, after the gas-oil ratio becomes too high, is of even more importance in the life of a slowly drilled field. Without such control, oil recovery will be decreased because of gas wastage. Owing, however, to the absence of an accumulation of gas on the crest of the structure, the principal advantage of near-unit operation in these fields, developed in the past, has been that due to limiting or regulating drilling. This has expressed itself in a satisfactory well-spacing program and a control of the rate of drilling in many near-unit California fields.

Outstanding among these near-unit fields is Dominguez Hill, where lease requirements in some instances and line agreements in others resulted in spacing the wells 610 ft. apart, or one well to 8.54 acres. At North Belridge, where the oil is heavy, the Belridge Oil Co. and the Reward Oil Co. made a 500-ft. line agreement. The Belridge Oil Co. spaced its wells 1500 ft. apart and as a result of this its wells are still flowing. Surplus gas in the North Belridge field is taken to the South Belridge field by this company and put back into the ground.

At North Belridge a deep sand, comparable with the Kettleman Hills formation, has been cored and is soon to be tested. Fortunately, the well-controlled land situation will not precipitate an intensive drilling campaign.

Another practice adopted in some of these near-unit fields has been the limitation of penetration of the oil zone. In 1924 the Shell, Union and Associated Oil companies agreed to limit their penetration of the oil zone in the Dominguez field to a thickness of 400 ft. The field was drilled up on this program. Subsequently one of the companies drilled several wells beneath this 400-ft. zone, but the other companies have thus far limited their drilling to one well for each company.

In the Inglewood field in 1925 when the production of the field had reached 116,000 bbl. per day, the practice was instituted of limiting penetration to a zone 1300 ft. thick, even though one of the companies

had proved a lighter oil and a valuable zone lying beneath this 1300-ft. zone. Subsequently, this deeper zone was proved to be 400 ft. thick by a second well which was shut in in 1926. This practice has resulted in setting up valuable reserves at greater depth in these near-unit fields.

In the Main Seal Beach field, the Continental, Standard and Associated Oil companies followed the practice of developing the underlying zone only after the near depletion of overlying zones, by using three stages of development. This not only eliminated a high peak production but it permitted the use of some holes for two deepening purposes. By this method two extra sets of wells were unnecessary.

A similar situation exists in the East Coyote field on the Hualde dome where only the Hualde and Anaheim zones have been developed. At West Coyote a recent deep test has proved a deeper zone. Since lease requirements have been filled, the zone can remain proved but undeveloped. At Montebello the same situation of proven reserves in deeper sands also exists.

Shields Canyon and Oakridge or South Mountain, both fields in Ventura County, were developed by Ventura Consolidated. These properties were merged with the California Petroleum and then with the Texas Co., becoming Texas Co. properties. The development of these two structures occurred through the period of higher oil prices preceding 1922 and furnished a sustained and substantial revenue for several years. Now the fields are being repressured by the Texas Co. to conserve gas produced with the oil.

When the Santa Maria field was originally developed there was competitive drilling, but since that time the Union Oil Co. has taken over many properties, thus permitting the shutting in of much of this field.

The control of the Lompoc field by the Union Oil Co. has made it possible to store gas from the Elwood field in the Lompoc field.

The storing of gas already represents a widespread movement which is coming into its own. It has been demonstrated as feasible at Montebello, West Coyote and Brea-Olinda. In some instances there has already been a marked improvement in possible oil recovery. Long Beach gas in large quantities has been stored by the Shell Co. in the Dominguez field. Ventura gas is being stored in the dry gas sand of the Buena Vista Hills of the Sunset-Midway field.

Unit Operation in Ventura Field

No better example of controlled drilling exists in the state than in the Ventura Avenue field. As they originally existed, the Ventura and the Long Beach fields seemed comparable in every way as to oil content and thickness of oil zone. To the end of 1929 their development had been as shown in Table 2.

TABLE 2.—*Development of Ventura and Long Beach Fields*

Fields	Producing Wells	Production, Bbl.
Long Beach		
1921	6	75,588
1922	156	18,560,595
1923	329	68,810,361
1924	525	60,119,659
1925	620	40,116,683
1926	711	37,931,964
1927	636	34,541,665
1928	844	62,467,105
1929	990	60,495,555
	Total.......	383,119,175
Ventura Avenue		
1916	1	2,650
1917	1	7,100
1918	1	23,609
1919	2	38,435
1920	5	105,185
1921	6	127,674
1922	13	685,247
1923	18	1,423,187
1924	27	1,831,903
1925	50	6,999,403
1926	76	14,795,495
1927*	106	17,808,704
1928*	141	18,920,942
1929*	137	20,934,388
	Total.......	83,703,922

* In these years a number of wells with high gas-oil ratio have been shut in. Eighty such wells are now shut in.

Ventura has been developed by regulated drilling since 1922, or through a period of eight years. There still remain from two to five years' more drilling to be done in this field. While more than 200 strings of tools have been run at one time at Long Beach, more than 50 strings never have been run at Ventura.

This field has demonstrated that unit operation, or some sort of control, is necessary to protect the deposit from waste. No matter where the first wells have been drilled on the structure, eventually they become most wasteful gas wells. The gas-oil ratio in wells increases from tenfold to twentyfold with age; *i. e.*, from 1000 to 10,000 to 20,000 cu. ft. of gas per barrel of oil. Such excess gas comes out of solution and leaves unrecovered oil in the ground. The remedy is to shut in the old wells when their gas-oil ratio increases above the general average of

new wells. A common ownership would permit this to be done; near-unit operation does not. Some think that the new gas law contains the remedy for such a situation; but thus far the remedy has not been applied.

Purpose of Unit Operation

Unit operation has been emphasized in recent years, as the discovery of so many fields has demonstrated the need of a complete control of excess production. This recent experience has demonstrated the inability of the industry to handle all of the oil that can be produced. Though not now generally accepted, the truth will soon be understood that the industry must leave the oil stored in the container nature made until the oil can be used. The continued storing of the produced surplus has ceased to be the remedy for overproduction. What once was thought to be a balance wheel has now become so heavy as to be a burden on a part of the industry and a threat to the remainder.

The same may be said regarding curtailed production. A heavy investment in oil wells exists, which calls for a return of the principal and a profit on the investment. At the slightest sign of an improvement, this poorly controlled production causes a breaking down of voluntary effort. It serves, however, to emphasize the need of a method that eliminates the heavy investment in drilling wells before they are needed and in storing oil before it can be used. Price cuts will inflict punishment without remedying the situation, but the purposes sought by unit operation can accomplish the same thing with advantage to all.

As important and as great as this benefit promises to be, it is well to point out that unit operation will pay its way in lessened drilling and producing costs and in added oil recovery. Particularly in California, where every field has lasted since its discovery to the present time, it is clearly evident that much oil must exist underground and that methods now unknown and now unthought of may yet come into play, if the deposit is protected against damage and is held in such condition that methods developed in the future may be brought into play.

In the past few years, for the reasons sketched above, the purpose of unit operation (even though not designated by this name) has been given much consideration in California. It has been and is being practiced as to several wildcat wells that have been drilled and areas that are being tested, as follows:

In Angiola, Tulare and Kings counties all leases were taken by a new corporation, one-fourth of which was owned by the Associated, Richfield, Standard and Texas companies. A dry hole was drilled in 1928 and 1929. Lease obligations were so taken that a slow development would prove the territory in zones. There was no consolidation of property interests.

At Carpinteria, Santa Barbara County, nine companies, headed by the Continental Oil Co., have arranged a controlled prospecting and develop-

ment program for nine state prospecting permits along the shore of the Pacific Ocean. Property rights have not been transferred, but a fund is set up out of production to be divided among the nine companies.

At Rimpau, Orange County, the Union Oil Co. and the General Petroleum Corpn. have each contributed one section of land and entered into a joint agreement as to the development of the 1280 acres, each paying half of the cost of drilling a wildcat well, which is now being drilled.

In Huasna, San Luis Obispo County, the Union Oil and the Texas companies pooled their leases 50-50 and drilled a wildcat well, each company contributing one-half of the cost.

At Oxnard Plain, Ventura County, the Standard Oil and the Shell companies have leased large blocks of land and have entered into a joint prospecting arrangement. It is understood that if oil is developed leases will be pooled and the territory developed as if it were held by a single owner.

Of the foregoing wildcat tests, the one at Carpinteria appears to be the nearest approach to unit operation, but it is not a true unit program.

The purpose of unit operation has likewise been sought in proven areas. At Kern Front in 1929, Brundred Brothers proposed unit operation of the properties of the 12 companies in this field. They claimed, as the advantages of the proposed unit operation, reduced operating costs, the need of fewer new wells and added oil recovery due to a proposed repressuring program. The project was considered by the 12 companies but was never adopted. Some companies were unwilling to give up control of their lands or to take stock in a corporation for oil lands owned in fee.

At Santa Fe Springs in 1928, repressuring of the Meyer zone as a unit was proposed as a means of avoiding the waste of gas that would follow the development of these deeper zones. The plan was accepted by all but four or five of the operators in the field, and 85 per cent. of the Meyer zone production was actually consented. An agreement was partly signed up. The matter did not go far enough to determine the reaction of the land owners to such an arrangement. So many interests were involved that there promised to be great difficulty in making such an arrangement without having some means of compelling the minority to join with the majority in reasonable conservation.

At Santa Fe Springs in 1930, the engineers of the Union Oil Co. proposed a unit operation and control of the Clarke zone. The same difficulties that prevented repressuring the Meyer zone will exist relative to the unitization of the Clarke zone, even should the gas law be enforced. The need of some action relative to both of these zones is still an important one, since the Clarke zone will produce a surplus of gas that can best be stored in the Meyer zone.

At Kettleman Hills in 1929, three agreements for a controlled development program were entered into relative to the North, Middle and South domes. No discoveries have as yet been made on the Middle or South domes and prospecting work on them has nearly ended.

At the present time the Kettleman Hills Committee is seriously considering two programs relative to the North dome; one for unit operation and one for controlled development. Where less than a year ago it seemed impossible for the Secretary of the Interior to harmonize views so as to secure the three agreements of 1929, it is now recognized that either unit or near-unit operation is a necessity. No matter what the final solution of this problem may be, it will be a big step forward in accomplishing the purposes of unit operation. An extensive drilling program will be avoided, revenues will be equalized, gas waste will be stopped and eliminated, and there will be no complete demoralization of the oil industry due to this great field of 16½ sq. miles. Each barrel of oil produced is equivalent to 1.4 bbl. of gasoline. The oil is 59° to 61° gravity and contains 90 per cent. gasoline. With each barrel of oil there is produced 25,000 cu. ft. of gas, containing 0.7 gal. of gasoline per 1000 cu. ft., amounting to ½ bbl. of natural gasoline with each barrel of oil produced. Uncontrolled, this field could supply the entire state with gas and gasoline and leave a surplus sufficiently great to demoralize prices. If some of the companies should hold out and refuse to enter unit operation, the situation is critical enough to make certain that some cooperative plan will be developed. This may be hastened by the enforcement of the gas law.

Conservation of gas is even more difficult to accomplish than conservation of oil. In the past 2½ years the overproduction of oil has brought about an enormous waste of gas. In a state where there is no good grade of coal, the importance of conserving gas is vital to its industries. Committees of operators and engineers, representing the entire industry, worked through the latter part of 1927 and 1928 in an effort to bring about voluntary cooperation to conserve gas. In this matter it finally developed, however, that cooperation was impossible without 100 per cent. participation. Participation to this degree was never attainable. The will of the majority was always thwarted by the unwillingness of a small minority. This situation gave rise to the new gas law of the State of California. If sustained by the courts, it furnishes the means of making all parties adhere to the need of the community that gas shall be conserved.

The New Gas Law

Under the new law, the blowing of gas to the air is prima facie evidence of waste. The law also contemplates a division of gas outlets and cooperative agreements for the conservation of gas. One paragraph in

it is directed to excessive gas-oil ratios in fields where oil can still be produced with a low gas-oil ratio. The state has applied for injunctions to stop the waste of gas at Santa Fe Springs, Signal Hill and Kettleman Hills. These proceedings are still in the courts.

Another paragraph of the law permitted a different type of action. By working along this line, the Director of Natural Resources secured an order in the Ventura Avenue field calling for the reduction of gas production there to the available outlets, plus a 10 per cent. working surplus. An average daily curtailment of 122,450,000 cu. ft. of gas has prevailed since Dec. 1. The gas production of the field was cut 40 per cent. and 82 per cent. of the former blow-off was eliminated. While gas production was cut 40 per cent., oil production was cut only 22½ per cent. Most of the gas conservation at Ventura was accomplished by the outright killing of wells having excessive gas-oil ratios. Of the 217 wells in the field, 137 are now producing and 80 have been killed. The gas-oil ratio of the field showed a notable reduction.

A successful application and working out of the California gas law should furnish sufficient justification for the adoption by Oklahoma and Texas of a similar practice. Unquestionably, the easiest manner in which to comply with the gas law is by means of complete unit operation. While unit operation is still rather revolutionary for various reasons, the gas law promises a new form of regulation that will make necessary near-unit operation and which will encourage unit operation. This sort of procedure can be applied to the existing fields where gas is still an important factor.

In new areas where the prospecting has not begun, a form of control might be established. R. E. Allen, engineer with Paul Grimm, Oil Umpire for Santa Fe Springs, has suggested that, in order to bring about a complete cooperation of all landowners, an exclusive franchise system could be set up covering each area to be tested, and that no franchise to prospect would be issued or granted until a uniform plan of development had been adopted. This would require legislative action and represents a step in advance of what the industry is probably prepared to accept. If voluntary action can be secured among the operators, it will go far to bring about a condition where the cooperation of all land owners may be sought. Experience has shown, however, that thus far in Southern California a 100 per cent. cooperation of many landowners can not be secured.

In most districts, the situation is not complicated, as it is in Southern California. Real estate values in many instances far exceed any possible oil value that may be set up. The limitation due to real estate values is becoming so pronounced and definite in the Los Angeles Basin that, in some areas, the oil man is no longer a welcome visitor. This serves only to indicate that, while unit operation may not be effective in this area of

high real estate values, a different sort of check will prevent a series of town-lot fields, similar to those that have been developed in the past 10 years. Then again it must be admitted that the Los Angeles Basin has been so thoroughly prospected that but few possible areas still remain.

Behind all of these developments and trends in the oil industry and all of the things that have been discussed herein is the engineers' conception of what an oil deposit really is. This view is indeed very different from the one so often expressed in court decisions, that oil is a fugitive substance and belongs only to the one who captures it. We may look forward, however, to the time when this old view will give way to the one upon which the engineers in the industry base their support of the purposes of unit operation.

[For discussion of this paper, see page 85.]

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Rocky Mountain.—Fred E. Wood, chairman, J. G. Bartram, C. E. Dobbin, Wilson B. Emery, Charles E. Erdman, R. D. Hawley, E. W. Krampert, Foster Morrell, W. T. Nightingale, K. B. Nowels, C. M. Rath, Earl Shoenfelt, J. W. Steele, E. T. Wilson, J. J. Zorichak.

Kansas-Oklahoma.—Committee members: C. E. Beecher, chairman, A. W. Ambrose, R. C. Hauber, Clyde Alexander, R. F. MacArthur, C. R. Swarts, M. M. Valerius, E. H. Griswold, G. S. Rollin, L. Murray Newman, David L. Trax, Richard K. Huey, Marvin Lee, Harry Johnson; others who contributed: E. A. Carr, Paul S. Ache, K. C. Slater, R. S. McFarland, J. R. McWilliams, Joseph Chalmers, Henry A. Ley, Dorsey Hager, H. C. George, W. K. Whiteford, L. G. E. Bignell, L. E. Smith, George E. Burton.

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Discussion of Unitization

[THE FOLLOWING DISCUSSION IS ON THE SUBJECT OF UNIT OPERATION IN GENERAL, BUT CERTAIN PAPERS ARE ESPECIALLY MENTIONED.]

G. O. SMITH,* Washington, D. C.—This program is itself a demonstration of the widespread interest in the subject of more efficient development and operation of oil fields. The statements of fact already presented and the views expressed are sufficient evidence that the engineering and economic principles fundamental to the idea of unit operation are much more generally accepted than they were even one year ago. And real progress has been made in putting these principles to the test.

No one realizes better than I that the fight against waste, whether physical or economic, must be waged in the front-line trenches: Washington at best is only an observation post. Yet viewed from this distance the advance made in the last few months has been notable and to a high degree encouraging.

Five years ago the Federal Oil Conservation Board, in its first contacts with the industry, raised the question, "How can new pools be explored without exploitation until new production is warranted by the country's needs?" Three and one-half years ago the Board, in its first report to the President, paid largest attention, among what it listed as fundamental conservation measures, to "cooperative methods in sane development of new fields." A year ago, in its third report, the Board again endorsed as the essential factor in conserving the nation's reserves of oil, "full cooperation in unit control, whether by voluntary agreement or by state enforcement." The function of this federal agency has been purely fact-finding and educational. The Oil Conservation Board early declared that the major part of its task was to help the industry "formulate the broader by-laws in the sense of conservation."

And now, after these five years of eventful history in the oil industry, may I size up the situation as I see it from the Washington point of view? First of all, and fundamental to a successful issue, I have observed in the industry a gradual acceptance of technical opinion as the guide to executive action; and this has at last led to some agreement as to what procedure offers most promise.

Analyzed in more detail, this highly desirable progress has consisted in "self-restraint actuated by enlightened self-interest." We see emerging the general desire of oil producers for efficiency in operation, which means low costs and high recovery. As shown by facts presented at this meeting, competition in drilling is in direct opposition to efficiency in oil production, in that such competition increases costs and lowers recovery. The only route to conservation of this natural resource and also of the capital and labor involved in making it available is through unit control, which substitutes cooperative, well-planned action for competitive, unregulated activity, forced by the individualism of a small minority of landowners or perhaps by a single operator. Or, in terms of actual experience, development of an oil field and its subsequent operation under unit control means the substitution of majority rule for minority rule, yet the minority enjoys to the full the resulting economic benefits.

So far as it affects the public interest, unit operation of oil properties deserves unqualified approval. It means more oil from the same area over a longer period

* Director, U. S. Geological Survey.

and at lower costs—that is practical conservation. It means underground storage of oil until it is needed for transportation to market—that is ordinary thrift, avoiding the large economic waste involved in above-ground storage. It means an adjustment of supply to demand, rather than letting surplus supply stimulate excessive demand—that is both good economics and long-range vision. You may recall that President Coolidge in appointing the Oil Conservation Board said: "Overproduction in itself encourages cheapness, which in turn leads to wastefulness and disregard of essential values."

If gas is considered along with oil, the case in favor of unit operation becomes much stronger. Gas has now come into its own, not only as a commodity of large value to the public and a by-product of large profit to the producer, but also what is of even larger importance, as the most efficient agent in producing oil. The escape of gas is therefore a twofold waste. And so it is that the new California gas law stands on good technology and good economics. That legislation was sorely needed in a state where in the later part of last year, although nearly one billion feet of natural gas a day was being utilized, as much was blown into the air as was used. In the Kettleman Hills in the same months nearly twice as much was wasted as was used, and now the ratio is even worse. Here, indeed, at present field prices, the gas with its gasoline content is worth much more than even the high-grade oil it brings to the surface. But prevention of such waste, which strikes at both the present and the future prosperity of California, is difficult if not wellnigh impossible under competitive development and operation of the old-fashioned type.

A happy sign of the times is the present activity of an engineering committee representing the operating companies at the Kettleman Hills. That committee, including several members of this Institute, after study of unit plans adopted or proposed elsewhere, has presented two plans—one providing for centralized control and unit management of the entire field, the other contingent upon full cooperation of the operators in allotting development and "holding production down to the minimum consistent with good practice."

The fact that the Kettleman Hills owners and operators face an injunction proceeding under the California gas law makes opportune this conservation movement, which was specifically provided for in the field agreement of last July. As has been suggested by Secretary Wilbur to the chairman of this committee, "If a properly worked out plan can be made a part of the court action instead of having something arbitrarily put on, it will mean a great deal."

This idea of self-regulation by voluntary cooperative action within the industry has been stressed from the beginning by the Federal Oil Conservation Board. The determination of equities among the owners and operators can best be made by themselves if only the "intense individualists" can be made to see clearly that unrestrained individual action threatens their own profits. Insolvency is a high price to pay for perfect freedom of action.

Moreover, the other phase of the question, the assurance that the public interest would benefit by unit control, has been fully discussed in the reports of the Federal Board. Even in an oil field potentially as large as the Kettleman Hills the possibility of monopolistic effects of widespread extent need not be feared, but any imagined undue and harmful influence upon supply or price could and should be avoided, as was suggested to the board by Mr. Hughes as counsel of the American Petroleum Institute, by bringing the voluntary cooperation "always under appropriate and adequate governmental scrutiny." The California law not only sanctions cooperation of producers, where nature has made the oil pool a unit, but in enjoining waste of gas this new law practically imposes some type of unit control. There need be no fear that observance of natural and economic law is necessarily in violation of statutory law.

H. L. DOHERTY,[1] New York, N. Y.—I want to show you the spirit in which I come to these meetings, so I will hold up a white flag to let you know I come in the spirit of peace, and that there is no rupture between me and the men who belong to this Section.

I want to put this one thought before the meeting for fear they might get the wrong idea of what unit operation is. When Mr. Hill speaks about these foreign pools being operated as units, I do not know whether there are any or not being operated as units, as I see the problem, because the unit operation of pools is something else than mere geography. From what little I know about the foreign field—and I did know a great deal about it four years ago because I had searched the whole world, as it were, to get information on the subject—there was nothing then in the real sense of unit operation of pools where advantage was taken of all the possibilities that are presented, by preventing waste of gas, and keeping the oil always being produced from the oil horizon.

I doubt whether any of us have yet gotten an idea of what the staggering wastes have been in this business; not only that, but I am very sure that by unit operation of pools all of these wastes can be prevented, provided we can develop the mechanical technique to take care of our very high pressure and very deep wells, in the matter of putting the gas back into the pool.

I know there are a great many technical men in this business who have not known what I was driving at, and I think a good many have thought perhaps that I have been impatient, and that perhaps I did not know exactly what I was doing. The truth of the matter is that I have had several pairs of pants ruined by trying to reform other industries I have been connected with, and I made up my mind when I started in on the oil business that I was going to accomplish it if I could without saying a word on the outside to the oil industry, and without saying a word until I had first converted the leaders of the oil industry.

Probably I made a mistake; probably I should have taken the thing up first with the scientific societies. If the real science of the possibilities of the development of oil could be visioned, based on operation by units, the maintenance of the oil in the condition in which it is found in a virgin pool, the results would be so sensational that I do not see how anybody connected with the oil business, connected with any business that uses oil, or anybody having an interest in oil, could do anything but advocate that it be done in that way.

I worked on the matter of trying to stabilize the oil business even before we got into the World War. I tried to do some work in connection with the war, and when the war was over Secretary Baker kindly offered to continue that work if I was willing to supervise it. I had been working very hard, so I said "Mr. Baker, I am just tired; I want to get a rest." But I thought there were one or two things I could start that would be important, and one of them was this matter of trying to bring about a reform in the oil business. I started to work in 1919 again, and started then by saying that in my opinion nothing could save us—in spite of the fact that we had a shortage of oil at that time and a price of \$3.50—from an overproduction of oil that would probably continue until we had so exhausted the resources of this country that we would reach the point of permanent shortage where our supply would be insufficient to meet our own needs.

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[1] In view of Mr. Doherty's pioneer work and early association with the plan for the development of oil fields as units and his insistence on better methods of conservation, he was especially invited to attend the sessions and to discuss these matters. The text covers the stenographer's report but is slightly revised by Mr. Doherty, who was not able to give the time necessary to make a systematic presentation of his views.—THE SECRETARY.

Then I began to try to convert the people, and you men know practically nothing about the work that went on behind closed doors, with the executive committee, a good many years back, or with a special committee that was appointed, and then another special committee which was appointed—and finally the rupture, the public knowledge of the split among the oil men, which was first known in September of 1923. So this is not new, and if at times I have seemed impatient, I am sorry.

But if it has taken this long—and I know a great many of you do not agree with me—to get this far, I am afraid I never will see the dream that I have always had in my mind that I would some day myself be the superintendent of an oil pool, and would have a place that would be a garden spot, with nice homes, cottages, women and children, and everything of that sort—which we can do.

Our present method, I think, is wrong. I have learned from long experience that when men cannot agree it is usually a case, not where one is 100 per cent. wrong and the other is 100 per cent. right, but where both are wrong. In spite of what I may seem to a great many of you people, if I am wrong I am willing to be corrected, and here is the place for me to learn, and you will find me most amenable to reason. Yet, on the other hand, I do not mean to stand still and allow this thing to drag and be confused. Many men have known of this terrible waste in the oil business, but they have not had a specific plan to correct it; they have not had the determination and were not willing to sacrifice enough of their own time and effort to bring it about.

I have been sick, as perhaps many of you know, for a long time. I have not seen my house or office for more than three years. I did make an announcement of some of my work in 1925, because at that time the Federal Oil Conservation Board was trying to get information about the production of oil, and I knew that the men who were asked to reply to many of the inquiries that were on the questionnaire could not possibly give an intelligent answer to those questions unless they knew that oil in a virgin pool was in an entirely different condition from the same oil after it is raised and in our tanks.

That is something of enormous importance, and from that work I announced that part, and I went on and did other work, which I hope to bring out before your society or before some scientific society. I think it will almost take you out of your seat to see how the oil pools have been made by nature, and it looks as if the aim had been to hand the oil to us on a silver platter.

The criticism that I have not explained as much about this as I should cannot be made by the men who have sat with me in the meetings behind closed doors. I did get to the point where I did not want to discuss detail because you can wreck a plan by discussing detail. When they passed the Federal Reserve Bank Law they did not name the 13 cities that were going to be the regional cities, because they would have wrecked the plan if they had. I finally went to work and tore up every plan I had so that I could say conscientiously that I had no detailed plan, because I realized that I could not discuss the details until we were ready to say whether we wanted unit operation of pools first.

I have been criticized for in turn criticizing the lawyers, and in some cases criticizing the court. On the other hand I have defended repeatedly the courts with the oil lawyers. A court cannot supply the vital information necessary to give an intelligent opinion in an oil case—and all of our laws have been made by courts and legislatures, and where the legislatures have acted they have really acted on what has been done by the courts in almost every case. The courts could not supply this information that we did not have. They cannot supply something that the oil men have not yet learned, but we do know now, and this is as certain as I am standing here before you, that there is no law of any state, providing for the production of oil, that is not in violation of the guarantee given to us by the Federal Constitution. You cannot develop, under the laws as they now exist, an oil property without depriving the other owners of that

property of part of their property, and that is one of the things that the Fourteenth Amendment undertakes to prevent.

We must change those laws or else go through a long period of years of chaos and litigation. And how much better it is to frame something and pass it now. I have never been an absolute stickler for Federal legislation, but I have said very earnestly to the oil men, and I say so still, that they will see the day when, if they use state legislation, they will regret it and regret it terribly. Why did I want the Federal Government to settle this? First, this is a national problem. It is not just something that we are interested in, although the oil industry has lost hundreds of millions of dollars by not taking hold of this thing and adopting it rapidly and quickly. Every other civilized government has taken hold of the oil problem. That does not mean necessarily that we can do it, because many of these governments are not constitutional governments. But there is an abundance to permit us to do it by our Federal Government, in my opinion, and I believe that it should be done by the Federal Government.

There are many and ample provisions in our Constitution not only to justify but make it the duty of the Federal Government to act. If it cannot be done under the other and more natural power it can be done by the exercise of the right of Eminent Domain. If we say, "All right, we are going to pass a law that compels the operation of these pools as a unit," we certainly then have no problem with any federal law or any state law. We will say that if this constitutes a "taking of property" the people can appear and say to what extent they are damaged, and then we will take care of that, as is provided for in the Fifth Amendment of the Constitution, which says, "and private property shall not be taken for public use without just compensation."

Now when these people come around and say, "You have insisted that these pools be developed as units; in doing that you have taken our property," we say, "Well, you are twice as well off, do you owe us money or do we owe it to you?"

If the scientific men in the engineering part of the oil industry will start to figure out what is made possible by the operation of the pools as units, and the utilization of what has already been disclosed, keeping the oil in the condition in which it is found, there can be no argument about what we should do for the good of ourselves and the good of the nation.

It seems to me there is a feeling on the part of a great many of the men in business in the oil industry that they are to control the scientific activities relating to the petroleum business. I do not approve of that, and I do not see why this association should not go into anything that really lies in the realms of science and engineering, if for nothing more than to give themselves credit.

California

L. L. Brundred,* Los Angeles, Calif.—Mr. Jensen[2] left out, I think, one important thing; that is, the few attempts that *have* been made to secure some cooperation with landowners by means of community leases. In a number of our fields we have as many as 25 or 50 of those 50-ft. lots thrown together, into one lease with the idea of drilling, one, two or even five wells to that number of lots put together. It has worked out well. Mr. Boyd can give a little definite information on a community lease arrangement that took place out there.

Also, Mr. Boyd might discuss the situation at Venice, where the Ohio Oil Co. has recently brought in a well of about 2500 bbl. on a brand new structure, right along the ocean.

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* Consulting Petroleum Engineer, Brundred & Brundred.

[2] Discussion of Unit Operation in California, page 69.

R. R. Boyd,* Los Angeles, Calif.—As Mr. Jensen has so excellently brought out in his paper, the failure of any important cooperative or unit agreement in California has not been due to lack of effort on the part of the operators. For the past 18 months a large part of the work of the petroleum engineer, engaged and employed by the large companies in California, has been in working out plans looking toward unit operation on repressuring or drilling, and in selling them to the executives. Something has been accomplished, although we have done little to which we can point as a real accomplishment.

We have educated a great many of the operators to the advantage of unit operation, and the example which Dr. Smith has just brought out, of the Kettleman Hills agreement, is going to be felt in added impetus to the other schemes now under consideration.

Mr. Brundred referred to the community lease situation in California, which perhaps was one of the earliest attempts at unit or near-unit operation in California.

During the years of 1921 and 1922, when the fields of Signal Hill and Santa Fe Springs and Torrance were being rapidly drilled, several companies succeeded in getting together, through the agencies that were employed in collecting leases from various individuals, a number of community leases; notably, one of the General Petroleum at Santa Fe Springs, and one of the Union Oil, I think, at Long Beach.

It soon developed, however, that the financial promoter was willing to pay bonuses for drilling sites far in excess of the possible value of the lots. This quickly put an end to the community lease idea, and the effects are still being felt. The idea was that the property owner is anxious to get a quick return, rather than long drawn-out revenue from his lots. There is a chance for some research work to be done on that subject now, to prove what the outcome really has been; and I expect to do that, if I ever have an opportunity. If we succeed with some of our committee work, I may be able to take up that branch of it. Perhaps it will be necessary to take it up before we can sell some of these ideas to operators.

The other thing that Mr. Brundred referred to is the prospect of a compulsory community lease at the town-lot area of Venice—the beach lots offsetting the land of the Ohio Oil Co., on which a good producer recently has been brought in.

The beach lots are restricted, and the city has authority to remove the restrictions as to oil drilling if it sees fit. The present plan is to allow only one well to a block, and all lots in those blocks must be pooled into a community lease. Under such considerations only will the city permit the removal of the drilling restrictions.

The latest development in that line, which is causing some controversy, is that the city insists on its proportion of the oil that underlies the streets and alleys.

Cooperation and Conservation

H. C. George,† Norman, Okla.—There is one phase of unit operation, cooperation and conservation, that has not been brought out. It came to me in connection with some research work relative to A. P. I. Project No. 33, and in view of the great developments in oil reserves, it is especially, I think, worthy of thought.

The oil man, even assuming that he will work and try to conserve our resources in connection with making a profit, has overlooked one thing. He is utilizing the gas to lift the oil where he can. Does it necessarily follow that he should do that, except that part of the gas which occurs in the oil recovered, representing the gas-oil ratio?

For instance, say you have an oil field with 300 lb. rock pressure. Why not take a field and make this experiment? Operate it with no well showing less than 300 lb.

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* Production Engineer, Richfield Oil Co. of California.

† Director, School of Petroleum Engineering, University of Oklahoma.

rock pressure at the sand; build up at a key well a pressure in excess of that, a pressure sufficient to lift the oil; then, that being the case, you will have no gas coming out of the solution within the sand. You will get a flow similar to the ordinary flow of liquids, or the flow of dead oil.

The thing that retards oil flow, the thing that government engineers in the past have maintained as preventing us from getting most of the oil, is the gas that comes out of the solution within the sand and obstructs the flow of oil to the well. Why not take a typical oil field at this time and experiment with it? Of course, it would be a difficult thing to do in the Oklahoma field, with 2200 lb. rock pressure, but if by doing it you can eventually recover three or four times as much oil, why not experiment?

Perhaps if we did do that, the government would finally decide that our natural gas is the major natural resource and the oil will take care of itself, if the gas is properly controlled.

H. L. Doherty.—I am fully convinced now that there are other people besides myself who are thorough believers in unit operation of pools.

There is one thing that I have tried to do for a long time, and you can consider the wisdom of it. I think it is a great mistake for the oil industry to speak about our present methods of drilling as competitive. I do not see how it can be spoken of as competitive drilling; it is more like warfare than anything else.

When we try to change our laws or our methods, or when we are trying to not make it appear that we are violating the anti-trust laws, I cannot imagine anything worse we could do than to say we are mollycoddles and do not want to be subjected to competition.

In other words, the present method of drilling is not competition, it is vandalism, and it ought to be corrected.

Just one other point: Every industry, every profession is likely to adopt something in a careless way. I do not like to see "gas-oil ratio" used often in the sense that it is used, because it confuses me, possibly it confuses other people, who are even more on their guard than I am.

I wish we could always think of the gas-oil relation in terms of the excess gas over and above the amount that is dissolved. That means that we must determine, roughly, the absorption of gas by each crude oil, for there may be no pool where the character of the oil and the character of the gas are sufficiently alike to know by any information we now have how much gas is dissolved in the oil except by an experiment. What we want to know is how much gas we are producing above that which is dissolved in the oil.

The last speaker hit on something that is very interesting. Theoretically, he is absolutely right, and I have the figures to show that the great pressure gradient close to the well brings about the separation of the gas from the oil, and the gas springs into a gassy form occupying a much larger volume, and theoretically, you can choke back the pressure and keep that volume from increasing, and get a bigger production than with lower pressure.

What we are doing mostly in what is referred to as unit operation is really nothing more than cooperation, and unit operation means very much more than that.

You have probably heard often of that decision of the court where one producer tried to enjoin a neighbor against excessive drilling. The court, not having any evidence before it that it was impossible for one property owner to protect himself under certain conditions from the drilling of his neighbor, said, "Why, the remedy is not to enjoin for excessive drilling, but to use offset drilling yourself." That is impossible. If you had a stretch of land through an oil field, a very narrow stretch of land, in one case that I assume, which I think was fair in every way, one landowner would get 32 times as much oil as he is entitled to receive from the land he owns.

It seems to me that so long as the matter of cooperation is a voluntary matter and not a compulsory matter, no one of us, if the law gives us the right to rob our neighbors, is going to forego his right to do it.

Definition of Unit Operation

J. B. Umpleby,* Oklahoma City, Okla.—The definition of a unit operation has taken considerably different shape in my mind as an engineer since this discussion started. It now appears that the consolidation of the several geographic units in a pool is only the first step; only the basis for unit operation as the engineer is interested in it. The engineer as such is primarily concerned with unit operation as a means to reduce costs and increase extraction.

I mention this because if it is the will of the Petroleum Division that the unit operation study be carried forward into next year we need a clear definition of the phase of the general problem that we are chiefly interested in. It seems obvious that our chief contribution can be made in that phase where our conclusions have greatest weight by reason of our special qualifications, not overlooking perhaps the many corollary phases, but recognizing clearly that as engineers the engineering phase is properly our field. I mention this not in a desire to direct the discussion but as a thought that arose as the summary was being given. The subject of unit operation is open for general discussion.

J. M. Lovejoy,† New York, N. Y.—Due to the demoralized condition of the industry as much as anything else, I think the matter of unit operation is now being considered by everyone connected with the industry. Committees have been formed in the American Petroleum Institute and in the Mid-Continent Oil and Gas Association to study this problem. The Board of Directors of the American Petroleum Institute have passed a resolution favoring the general principles of unitization. The industry probably looks to the Petroleum Division of the A. I. M. E. more than to any other group for facts, and particularly technical facts, in connection with this entire matter, and I think that the Petroleum Division should lend every effort to assemble, publish, and distribute all the data that can be obtained on this important subject.

Criticism of Reported Advantages

F. J. Fohs,‡ New York, N. Y. (written discussion§).—I wish to confine my criticisms to the dogmatic statement of advantages of unit operation. I appreciate that it was necessary for the authors to state rather dogmatically their conclusions to put across their points. I regret that I can not be present in person to present the following, in order to show that many of their dogmatic statements are not warranted and that others require a much more considerable experience and gathering of facts than are now available on which to base conclusions.

The heading "Producer" requires division into "Crude Oil Producer" and "Refiner" and then a consideration of points under each because the interests of these are not always the same. There appears much probability of fact in the following subheads under Producer: (1) Less capital investment required; (2) lower development cost; (3) lower operating cost; (12) saving on pipe lines and storage tanks (here it would apply

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* Geologist and Petroleum Engineer. Presiding officer at the time of these remarks.

† President, Petroleum Bond & Share Corpn.

‡ Consulting Oil Geologist.

§ This discussion refers especially to the paper on Principles of Unit Operation (page 105).

to oil producer only, however); and possibly also in No. 6, under General Public Welfare "A longer period of dependable domestic oil supply."

No. 1 under Consumer—"Greater assurance of permanent and stabilized supply," No. 1 under Royalty Owner—"Stabilized crude price structure," No. 1 under General Public Welfare—"A great industry better stabilized"—are all part of a larger problem; that is, unit control if made general would be only one of a considerable group of factors necessary to stabilization of the industry and its supposed benefits.

All other points made by the authors are open to question and some of them warrant six question marks.

As to the Consumer—lower average cost over a period of years involves the question of what period of years—certainly the consumer is getting gasoline at a price lower proportionately than he is paying for most commodities. In the instance of monopolistic control, unit control must tend toward increased monopolistic control and thereby have just the opposite effect to that suggested upon both consumer, general public welfare, and also on the producer, especially the small producer of crude, and probably also will prove a detriment to the small refiner.

Under Producer, No. 4—"Products would be made more responsive to the producer's needs"—is open to question. It might prove helpful to some refiners, but will it equally to producers? Under Producer, Nos. 5 and 6, and under Royalty Owner, Nos. 2 and 3—"Increased acre oil yield" and "Increased gas value"—are very much open to question and can now only be a matter of opinion. Much additional fact gathering is necessary here.

Both in the matter of Crude Producer and Royalty Owner, interests we believe would be less salable, except in exceptional instances.

The independent oil producer would, except where he controls the unit, have less actual control over his business than formerly—in fact, his interest would be more a minority interest than a business.

More dependable crude supply to some refiners would be a correct statement. Saving on plant capacity might affect producer, chiefly in drilling equipment, and does not touch refiner.

That the royalty owner has a reduced risk and an interest more salable is especially open to question, and if this is so it follows that it would not be a better collateral.

Under heading of General Public Welfare, No. 2.—"Stabilized labor conditions in the industry"—would mean stabilized for a much smaller number of workers. No. 3., "Permanent neighborhood industries on account of steady gas-fuel supply," because of distribution of new gas lines carrying gas great distances is again open to doubt. No. 4, "Permanent communities," at best would be semipermanent, not permanent. No. 5 "An assured domestic oil supply for national defense," involves very much more than what is suggested; it would require definite reserves to be maintained for government use in war only.

A reduced speculative spirit would kill the incentive to production by any but refiners and make the actual cost probably higher to large refining units than now, since the small producer now bears a considerable part of such expense, because of the incentive of a possible rich find. Vast oil organizations and monopolistic tendencies would enhance rather than reduce, and thereby create a still greater need for government supervision, and finally small businesses would be greatly reduced in number instead of finding increased opportunity.

I am specifically opposed to this Division passing any resolution which would approve unit control, because the accumulation of data thereon has just begun, so that our facts are still meager on factors such as reduced cost, especially meager as to recovery. Besides, it is out of keeping with this body, largely a research and fact-finding organization, to sponsor a resolution covering points that belong to executives for decision, or are of a propaganda nature. I am heartily in favor of approving

work done by the committee, and of continuing it to make further studies and reports and also of publication of what it has done—a progress report only, as a *Technical Publication*.

J. E. Pogue,* New York, N. Y.—Will you permit me to disagree with most of the objections offered by Mr. Fohs? It seems to me that the principle of unitization is the most important new trend coming into the oil situation. It appears probable that this trend will continue and that we will ultimately be proceeding on the principle of unitization as a matter of course. By the process of evolution alone we will end with unit pools, for the reason that competitive pools will be depleted more rapidly than unit pools. If unitization gave the industry no other advantage than the one of greater ability to retard the rate of extraction, unitization would appear amply justified, not to mention the fact that oil can be produced at a lower cost from a unit pool than from a competitive pool. There are already sufficient unit pools, especially abroad, to set up the economic force of differential cost, which is perhaps one of the most powerful forces in economics, and this force is inevitably working in favor of further unitization.

C. P. Watson,† Fort Worth, Texas.—It has been suggested that this body confine itself to a fact-finding body. Had the engineers confined themselves to fact-finding in connection with gas-lift in the Seminole field, we would still have been in ignorance as to the possibilities of gas-lift. I think the same thing applies in this question of unit operation.

J. B. Umpleby.—That point is well taken.

E. R. Lilley,‡ New York, N. Y.—I agree in part with Mr. Pogue. I agree also in part with Mr. Fohs. There are two important questions. One is the question of the desirability from an engineering standpoint of operating a pool as a unit. Of that I am entirely in favor. The other is a question of economics. Immediately after the widespread use of the unit system of development, we should anticipate better prices for oil and more returns from investments in oil-producing and royalty properties. However, there is a question as to whether this betterment can be considered as of more than temporary value. Let us not forget that there are many companies producing in foreign countries under the unit system of operation, and that they are all producing large quantities in a depressed market today and are expecting to produce large quantities next year.

I do object to the term "unit operation" as it is commonly used in the oil press today; namely, as a "cure-all" of the ills of the industry. It is a step forward; it is an ideal for an engineer, but it is not going to cure overproduction, let us not put ourselves on record as supporting unitization as a cure-all. As an engineering ideal, fine!

J. E. Thomas,§ Fort Worth, Texas.—May I ask Dr. Lilley to name one, just one unit-controlled oil field in a foreign country, which is planning to produce a larger quantity of oil on a depressed market next year, because I want to sell that stock short.

E. R. Lilley.—The Anglo-Persian Oil Co. will.

H. L. Doherty.—I did not intend to speak again but I always want to be helpful if I can be helpful. I do not want to crowd my views on to anybody who does not

* Consulting Engineer.

† President, Federal Royalties Co.

‡ Associate Professor of Geology, New York University.

§ Thomas Petroleum Corpn.

want to hear them. I would suggest that the audience be divided into two groups: the ones who believe in some of the things I do, and those who do not. Then I could speak in proper terms to both.

I have made an effort in some cases to make my work recognized, because otherwise it might be thought that I had tried to put over an impractical plan and that I could not be potent or helpful in some of the work I still hope to do for the good of the petroleum industry.

I want to start basically by saying that the petroleum industry has had many years of very trying conditions, and for fear someone will be mistaken and feel that I am not actuated by the good of the industry I will say that for 10 years, to the knowledge of some of the men in this room, I have predicted with accuracy just what has happened. Having believed that, I have governed our oil operations accordingly. I wish even those men who have been unfriendly to me and have made it difficult for me to express my ideas could also have seen the possibilities of this trouble. I feel sorry for those men, as we know there are many who are on the edge of the abyss with this last cut in the price of oil, and I would like to see this industry where it does not have to cut its own throat.

This industry is in serious trouble; it has been in serious trouble for a great many years. Certainly we cannot stand here and say, "Well, this is no concern of ours." I was astounded when one of your prominent members said that the proposal for the operation of pools was so new that we knew nothing about it. He virtually said, "Let us delay action." We say we have not got the time.

If a man came to you and said, "I am hungry, I must have something to eat," and you said, "Come around next harvest and I will see what I can do for you," that is what you would be doing to men who are facing bankruptcy in the oil industry.

The work that I have done has been nothing that I particularly want any credit for. I started into this work. I carried it on to the point where my own reputation was involved, whether I was sincere and whether I was honest, whether I was practical, and whether it was a proper thing for the industry. If any plan can be suggested that will take care of the difficulties of the petroleum industry I will be the first one to endorse that plan and use it. Not only that, I will support that plan even if it is not equal to the plan I have suggested. I had nothing to gain from this. While my associates and competitors were busy grabbing for money I worked on it to my own detriment.

In the first place, I would like to be known as a scientist and engineer. Some of us do not have the good fortune that many of you men have had and perhaps my work has not been sooner recognized because I am unable to speak the technical academic language you expect to hear. I have not been inside of a schoolroom since I was 12 years old. Necessity has often compelled me to do various kinds of work. Not only that, but I have had other things to look after and take care of, and I have had to devote a great deal of my time to business. However, I have always tried to contribute what I could toward scientific development and good engineering, and I am doing that now although I have been through a very long period of inability. I am back on my feet and I hope I can do something not only for the industry but something for the related industries as well.

Dr. George Otis Smith has hit the nail on the head. In trying to make a different plan for the development of oil, I have merely tried to get in harmony with nature. No man in the world can divide this oil in the way we divide our surface rights, and while I do not care particularly what word is used, I might say to you gentlemen who suggest the word "cooperation" that after my opponents had condemned the idea of the operation of pools as units as I first suggested, and later as the unit operation of pools, they then coined and used the word "cooperation" for some time in the

development of pools; or applied the word "cooperation" in different ways. Now they have abandoned that. I do not know why. You are two years late at least.

I care not what it is known by. I do know that the best engineer in the world cannot do proper engineering work and get the recovery of oil that he should, save the gas or things of that sort, unless that pool is operated as a unit. No matter how good an engineer may be, he cannot do it by operating oil pools as they are operated now.

I am not striving simply for the intelligent operation of pools; I am striving for the least possible—I was going to use the word "conservation" but if that is objectionable to some I will omit it—waste. In Mr. Oliver's paper,[2] although it was not brought out at the meeting, one pool was mentioned at which a core from a drill showed 94 per cent. of the oil still remaining in the sands. I have good reason to believe, gentlemen, that practically all of that oil can be taken out. Instead of leaving one barrel of oil in ten, as has been done in a good many pools, we can take nine out and leave one or less there. Not only that, but I believe we can save all the natural gas. I doubt whether there is a man in this room who has any comprehension of the gas that is wasted. I doubt if there is any man in this room who has any idea of the importance of gas in relation to oil. I am going to try to get definite knowledge of it, but unfortunately I cannot get sufficiently definite knowledge about the oil business to speak about it without being in danger of being contradicted simply because accurate and definite observations cannot be secured under the frenzied methods we are now forced to employ.

I do not believe there is a man in this room or in the oil industry who can tell the pressure of a single well, make it stick and prove that he is right—that is, the pressure of the oil in the ground—because as the pressure is measured I do not believe it is accurate. Therefore, I have not been able to use the pressures reported to me without the fear that others would dispute them. But I want you to know the relative importance of natural gas in oil. I suggest that you take all the oil, as I have tried to do in Ohio, that was ever produced in Pennsylvania, New York, Virginia, and Kentucky, and then contrast that after reducing it to an energy value to the amount of energy produced in the form of gas in those same states.

We had a pool at Smackover. I bought a majority interest in a company that had a little gas company down there. They found a lower oil sand and dissipated all the gas in a few months and we had to run a pipe line to another gas field where there was no oil, for there was not enough gas to be had in the Smackover field even to supply fuel for oil well drilling. At Cromwell they dissipated gas at a rate of 1,200,000,000 cu. ft. a day, equivalent to 200,000 bbl. of oil or 48,000 tons of coal. These wastes cannot go on. I believe the industry is endangered by permitting it. This whole thing has unfortunately got off on a basis of prejudice, which I did not cause but which came about through other things that I had nothing to do with. Yet I have been compelled as it were to be the "goat."

My work in this thing has been most interesting. I have not brought it all out. I will do it and try to make it as beneficial as I can to those who want to pursue this work, and if it is of no value I want at least the courtesy of being told why it is of no value, not simply a broad sweeping condemnation of it. I was astounded when I was called before the Federal Oil Conservation Board, to have one of our Petroleum Institute directors deliver a most impassioned speech on the benefits of cheap gasoline to the public. He warned the members of the Federal Oil Conservation Board that they should do nothing that would prevent a low price of gasoline. Well, if that man was honest and sincere and wanted to put down the price of gasoline and keep it there he was certainly successful.

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[2] See p. 105.

I still claim that every advantage that has been cited for the unit operation of pools is true. I do not think there are any disadvantages. I want to get away from any prejudice I may have. I keep constantly thinking I must be wrong because I am constantly saying about every other controversy that when you see a controversy that lasts a long time it is a case probably where both sides are wrong. Why have we not been able to agree? Because the oil men after talking to me for a while would not talk to me any more. Even when I told them I had to go to the Government to prevent this waste they laughed at me. They did not think I would get any place.

Then since we did get some place, when we took the thing up before the Board of Directors in the meeting in 1923, after it had been under discussion for a long time—and nobody seems to realize that—they have never given me a chance to talk. I am not allowed to talk to the lawyers. When they hired special counsel to go before the Federal Conservation Board I was there to answer him, and they all know it. They would not even give me a brief and the counsel walked out before I could ask him a question.

At the Fort Worth convention of the American Petroleum Institute Tom O'Donnell took all of his presidential address to attack me and attack my plans. Then Judge Beaty got up and made another speech. I thought it was about time, in justice to what I believed was right, to ask to be heard. The audience was willing to give me a chance to be heard. The directors said, "No, you will have to reply behind closed doors at Colorado Springs."

If I have been allowed to talk at all it has been behind closed doors. I am able to buy and am willing to buy space in the newspapers to talk. I have been refused the right to buy space in the oil newspapers. They are willing to let me have the space and probably they would be willing to let me write a report or a discussion of the report of Committee 11 if they could dictate what I should say. When the oil journals tell me I cannot have space unless they can censor my copy they are just going to drive me to use other papers. For instance, all the oil men have aired my faults and such things and I in turn have had to respond in the best way I knew how. I do not see why that is necessary. I do not see why a few of us could not have sat down together and have been fair and sincere with each other, and have agreed what was the thing to do.

Do not forget that no man has brought out a single thing to take care of the ills of the oil industry, which have been terrific. Why could we not have sat down and talked it out? I have not been vicious, or anything of that sort. I did say, and I mean it, too, that I am going to carry this thing through if I have to fight. I hope I will not have to, but I have gone through this campaign for years and no man can point to a single statement that I have made that I cannot make again. I defy them to repeat the statements that they have made. What an organization like this wants is the truth.

When I was trying to talk to these men, and we were behind closed doors, they told me there was no waste; they told me there was no overproduction, and they told me many other things. The next day they said, "There is no waste; there is no overproduction. Didn't you hear us vote 'yes' unanimously that there was not?" I said, "I could not say that today even if I voted with you." The voting went on for two days 34 to 1. The next meeting it was 29 to 1, and they told me there was no waste, no overproduction; there was no nothing.

This thing has gone on for years. When I said, at Altantic City, "Gentlemen, your own engineers will not back you up in what you are saying to me," one of them said, "You bet your life, my engineers will!" And that same thought was echoed through the minds of more than half of those men.

I may be a poor engineer but I have worked as an engineer and I believe it is a great calling. I have said without trying to disparage the church or the courthouse that you could write above the door of the research laboratory more truthfully than perhaps any place else, "This is the place where we search for the truth." That is what every scientific man must do, every engineer must do. No man controlled my testimony or what I did as an engineer, no matter who paid me, and I worked as an engineer and I have needed my salary and needed it very badly, too.

I will say I am wrong if you will show me where I am wrong. What I have tried to do is make it possible to get the oil out and do it along sane lines. Perhaps any of you men could have done the work I have done and done it much better. I went to many technologists and said, "How can you have a well of this size, a flush production of this amount and, on the other hand, your tests in the laboratory show such a slow movement of oil through the sands that either one or the other cannot be true," but they never told me. I sat down and figured it out for myself.

Then I went to work and had the pressure apparatus built to show what did it, and it showed pretty plainly that at least the gas was an enormous factor, and there was such a remarkable change in the viscosity and behavior of the oil that it could account for the size of our flush wells. Unfortunately, I had to announce that work a long time before I was ready because I felt it was only fair to the men who were trying to answer the government questionnaires. Nobody could answer those questions and give the right answer to them unless they knew the condition and behavior of oil in a virgin pool and nobody knew some of these most important facts until I disclosed my work in a letter to the Federal Oil Conservation Board in July, 1925.

I have had a quarrel with all the lawyers. They have lined up the whole legal profession against me. They have backed away from their original assertions one by one and they have to back away from all of them, because I have stood on this unit operation of pools largely because I knew I was in harmony with nature. Men cannot make laws; they cannot do engineering contrary to natural laws. There is no law today on the books of any state in this Union that permits the development of oil pools without one man depriving his neighbor of his property, and those laws cannot stand with the guarantees in our Federal Constitution and the scientific knowledge we already have. We must have laws relating to oil as a property the same as other laws, and I for one do not want to go under the police laws of the state. They are dangerous. They are in a way that you can violate both the state constitution and be supported by the state courts, and violate the federal constitution and be supported by the federal courts.

I want legislation defining the ownership of oil properties as clear and as free from interference as when you own a building on this street, and much freer, because the principle in law has been established long ago that one neighbor cannot use his property to the detriment of others.

I know that a great many men, men for whom I have a great respect and very high regard, do not believe in some instances as I do. Mr. Oliver, for instance, does not believe in compulsory operation of pools by units. But our present laws cannot be sustained. We must have some laws, and we will have to have that kind of a law, in my opinion. If we go to the state courts for laws we will not get uniform laws or good laws. If we go to our federal government, we will at least have harmonious laws. We know the federal government can better tell how to pass those laws than the states can. We know that every other civilized country in the world is making oil its principal problem. Our government must be loaded with the responsibilities of our oil problem. There are good reasons for it; I could tell a whole story on that—about how one nation took away an American oil deposit where the practice is in absolute violation of its agreements with our government, and our government would not move a finger to protect us. That nation was the one nation of all others

we would sooner not see have an adequate supply of oil; especially obtained in that way.

We cannot expect the men who have a right by law to rob their neighbors to refrain from that right when they have been robbed themselves yesterday and may be robbed again tomorrow. I have shown—and I do not think any of you engineers would disagree with the figures—that a man owning a small piece of property, we will say a narrow strip, can get, under certain assumptions that I had to take and which I think were entirely reasonable, 32 times as much oil as the amount that originally lay under his property.

Now how are we going to get voluntary cooperation when a condition like that exists and when one man is empowered by law to rob another? So far as we now know there is no way to cure all of these evils except by operating pools as units. Every pool you go into is a new pool. You have a new set of landowners to deal with. You must not only get the consent of all the lessees but you must get the lessors, you must get the property owners to agree. You must educate a new group of property owners in every pool you go into.

I stand now as I have always stood, ready to try and plan, help, do anything I can to relieve the bad conditions that exist in the petroleum industry. I am willing to support anybody else's plan, but I want to say just one word: that the men who are neither getting a plan of their own nor coming out against the plans practiced at present are the greatest enemies in the progress we may make in this direction. Get on one side of the fence or the other, and then we will know how to act.

J. B. Umpleby.—I thank Mr. Doherty on behalf of this organization for his discussion. I may say in passing that in my opinion no published contribution has influenced thinking on the subject of reservoir forces more than the one that came from the Empire organization on the relation of gas and oil in the sand. I understand from the men who did the experimental work that Mr. Doherty defined the problem in detail and that he is the man who should receive chief credit.

Cautious Progress Urged

E. Oliver,* Ponca City, Okla.—There is a word of caution I wish to urge. As in all new movements, mistakes will occur and prejudice will be thereby aroused, all because of lack of understanding on the part of some operators of dangers to avoid. A certain engineer in whose judgment I have much confidence opposed the idea of unit operation because of the way he thought it would work out; namely, that in many cases only a few wells would be drilled on the structure to test it out, with the idea of holding the structure mainly as a reserve; that these few wells would be operated and through them the gas would be permitted to escape and the pressure would be gradually lowered on the reservoir without much oil being removed. Of course, in that case the oil intended to be kept as a reserve would be deprived of the pressure necessary to move it through the sand when its extraction was desired. With lowered pressure gas would pass out of solution and the oil would likewise be more difficult to move. In this I think he pointed out a real danger.

One of the first things we should attempt to do in promoting unit operation is to get across the idea of the importance of maintaining pressure on the reservoir at all times. There is danger that we are likely to influence operators into blocking up acreage and drilling a few wells, keeping the remainder as a reserve, and through those wells gradually letting the gas escape. Naturally under those circumstances they will not get the oil later.

* Consulting Engineer.

E. R. Lilley.—I am sorry that the word "control" was introduced into the unit operation discussion. I can visualize Brazil overwhelmed with coffee, Chile heaped high with nitrate, the difficulties of the British attempting to control tin, the failure of the rubber combination, and the breakdown of the Anglo-Italian sulfur organization. However, I am not entirely a pessimist.

There is one thing that does not seem to have been brought out. Possibly 40 or 50 years ago, the quantity of oil in sight was as great in relation to the demand as the quantity in sight is today. In the intervening period this was not true. In 1920, we were decidedly afraid of the situation. There was not enough oil in sight to guarantee continuance of the oil business. Because of this, land that was thought to have oil possibilities was given high speculative value. Since that time we have added steadily to our supplies of proved reserve and potential oil lands. Yet, some individuals, or some groups in the oil business, have maintained this high speculative value on oil lands.

The periods of overproduction are felt first in the less organized portions of any chain or sequence. In the oil business the producers were hurt first; the effects upon refiners and marketers were not felt until later. For some reason purchasers of crude, that is, refiners, seem to have failed to realize that the quantity of oil in sight is tremendous. We have plenty available for the next five years and, in addition, much for the years following. This means, of necessity, that we must revise our methods of evaluating crude. Those who have been making money despite overproduction, namely, the refiners and the marketers, are now feeling the effects of that overproduction despite the superiority of their organization over that of the producers. The optimistic note in the whole chain is sounded by the fact that when the last of the chain begins to lose money the true remedies are applied and profits are again in sight for all.

A. C. Lane,* Tufts College, Mass.—I do not think you can avoid the word "control" or something equivalent. Years ago, when I was state geologist of Michigan, a man had a flowing well and his neighbor down the slope put down a well which flowed a 2-in. stream, to feed one cow and five horses. The neighbor up the slope put in a plug, which left plenty of water to keep the trough full, but there was feeling between the two neighbors and the other neighbor knocked out that plug. The result was there was a law passed through the Michigan Legislature that to waste water under those conditions was a tortious act. This means you can get a legal remedy for it.

I remember also that something like a quarter of a century ago I told the people down in Saginaw there was a good chance of getting oil and gas underneath them. As a matter of fact, at a dinner at which I was called upon to speak, at one o'clock in the morning, I remarked that if they ever ran out of other fuel they could strike a flow of gas. But I also said I hoped they would not strike that oil until they had changed their state laws to prevent overproduction, because that oil field was directly under the city of Saginaw, which was all cut up into city lots.

It took them some time to develop the oil field, but they did not change their laws, and the result is about 300 wells were put down where they would have made good profits on 20 to 50. I doubt whether many of the stockholders have got their money back. Again one farmer can hold out and refuse to lease. Then when a pool is struck he will get more for his lease and he will tell all the other farmers what fools they were to go in sooner.

Of course the compulsion, the control, has got to be both ways. If you will tell a man who will now stand out from your unit that he cannot go ahead independently,

* Pearson Professor of Geology and Mineralogy, Tufts College.

you must also give him some sort of a right to get his share of the unit. But after all you must have a certain amount of control if you are going to have the most economical management of the property.

FINANCIAL ADVANTAGES

L. W. MAYER,* New York, N. Y.—Listening from the sidelines, there is one thing that impresses me; that is, attending these meetings almost every year for a long time, there seems to be considerable uniformity in hearing these very depressing remarks. I think we have heard them now for at least five or six years. On the other hand, it is hard for the outsider to reconcile this depressed condition with what seems to be increasing profits by the oil companies, reports of which have come to our attention.

Of course we do not see the reports of all the oil companies, and I suppose the answer is that the industry as a whole perhaps is not as profitable as it appears from the particular reports that are published most widely. However, the situation is probably no different from any other, and the impression is definite that the industry is a profitable one. If the reports are not correct, of course that is something we would want to know, and if they are correct, then why all the depression in the oil industry?

M. G. CHENEY,† Coleman, Texas.—Following that idea, I wonder if we could not hold one of these meetings in September or August, when we are using most gasoline, giving these economists more cheerful current figures to work with.

I think all of us will go home to our respective duties more and more impressed with the benefits to be derived from unit operations. I might speak as one representing the smaller operators. Dr. Lahee reported practically all smaller operators opposed to unit operation. We have been in four unit operations during the past two years and highly endorse them. Our own experience is particularly satisfactory. However, unit operation is still in the test period. It is a new thing and hence is being watched especially closely by all operators. I have talked with and tried to learn the opinion of our several partners in these units. For the most part the results appear highly satisfactory. It appears to us that the success and adoption of unit operation rests to a large degree on how much good faith is used in its administration. The controlling operator must carry on carefully as to costs, for an overcharge, while insignificant compared to the advantages gained, being unjust is bound to create ill feeling.

The operator and all interest holders must use good faith in all respects. We note that some of those who urged us to go into these unit operations do not seem to play as fair as they might. On blocks owned or controlled entirely by them we read that they drilled during the past year 44 wells on one block and on another block 77 wells during the second half of 1929 (just prior, incidentally, to discovery by them that too much oil was being produced and that crude prices must be cut) yet strenuously objecting to activity on our block in which they held about 10 per cent. interest. As a result of such attitude on the part of major companies, although many proved locations in shallow sands remained to be drilled, but three wells were drilled on our 2000-acre unit and these apparently only because offset requirements had to be met. If these larger companies are really as interested in unit operation as they profess to be they should show good faith in their apportionment of operations on all blocks in which they are interested. The main objection to drilling on the 2000 acres was that the oil was not needed. This objection to drilling should apply to the blocks owned by two operators or one operator as well as to blocks in which each has only 10 per cent. interest. Smaller companies have but few properties and must depend upon reasonable development. Perhaps inclusion in the unit contracts of a minimum rate

* Mining Engineer, Rogers, Mayer & Ball.

† President, Anzac Oil Corpn.

of drilling would lead to less friction from this cause. As stated above, unit operation is undergoing its critical test period. Its widespread adoption is doubtful, particularly by the smaller operators, unless all interests feel confident that such cooperative work will be carried on entirely in good faith on the part of all. Personally, we are highly in favor of unit operation and confidently expect to see its adoption generally by both large and small companies and operators.

C. P. Watson.—Is it not the idea of this meeting that the question involved is to show the economic benefits, rather than the legal and physical difficulties in putting into operation the unit method of development?

Regarding Mr. Mayer's remarks about the profits of certain oil companies, perhaps the engineers are attempting through efficient methods to show even better profits than the financial statements which he examined.

L. L. Brundred.—At first it might appear that I spoke a little bit hastily about the situation in California, but I just received a telegram from my brother in which he says things looked rather blue. We too have endorsed unit operation. It is just as sound in our opinion as the old adage that we eat to live rather than live to eat. We have a situation at Santa Fe Springs that I would like to bring out. Mr. Doherty covered the situation in the abstract. A well there was producing 800 bbl. flowing perfectly clean oil, 32.5° gravity, nothing wrong mechanically with the well, and just because somebody else about five or six lots away drilled deeper and happened to hit the top of a new zone, but had not produced it yet, this 800-bbl. well was killed. I happened to be at the derrick when the order came down to kill it.

Take also the Meyer zone, probably 400 ft. thick, perfectly good, very little water encroachment, nothing to damage it at all, and yet it was mudded up and ruined for future production in going down for the "big stuff." The answer was at that time, "Yes, we can go back to it." I think engineers who have had actual experience in the field know that it is difficult to go back to a well that has been mudded up in that way. The same thing happened at Signal Hill time and again. I happened to be on a well that was killed making 1200 bbl. I know of a whole lease in which about 2400 bbl. were completely abandoned because somebody else with a little bit stronger urge, with a little bit tighter purse string, went on down, forcing this company to do likewise.

In the Meyer zone, at Santa Fe Springs, we had a production of 35,000 bbl. per day. What have we today? Practically all of it is gone because one company goes down and uncovers a new zone during an economic depression. Then it was "off to the races." It was just whoever could find the deepest zone. The last attempt now is down around 9300. Any "auditors" who tried to pay for a 9300-ft. hole would soon realize that good-sized production is needed to do it.

There is a contributory factor in California; that is, the way oil is purchased. Oil is purchased first in the Eastern states on credit balances and they have a control over the situation, not only through price but by storage charges. When oil is put into pipe lines, you have to pay fixed monthly storage.

In the Mid-Continent it is purchased on division orders. The pipe line reserves the right to prorate, and does so. There are two controls there—proration and price reduction. In California, the bulk of the oil is bought under contract. In many cases no matter what the size of the property, 10 acres or 100 acres, the purchasing company has to buy every single barrel of oil that is taken out of that property, and it gets to be a serious matter when there are 4000, 5000 and 7000-bbl. wells on four or five lots.

That is what the oil companies out there are faced with. They tried first curtailment of Santa Fe Springs. That did not work. Then they tried a state-wide curtailment, which did not work, and all the time purchasing companies were doing

their best to stave off this deplorable condition. Finally they could not stand it any longer and they let the producer have it!—forty and sixty-cent oil!

Necessity is the mother of invention, and a good many of us after we had been burned on a stove did not say, "Well, we will do it again." We kept away from that stove. The California operators as a result of that drastic price cut are struggling to get the situation into hand again.

They are now trying a state-wide curtailment again. We hope it will work out. California, unfortunately, is the key to the situation; at least I think Mr. Thomas and some of the other economists would agree to that.

Our storage situation is another angle. A short time ago we had approximately 40 odd million barrels of storage of which only approximately 20,000,000 could be used at the present time on account of the condition of the tanks. Of that, a very large percentage is earthen storage. You can not run 32°, 35° gravity oil into earthen storage. Therefore much of the light oil was run through refineries so that the fuel could be stored in earthen tankage and the smaller percentage of light stuff stored in tanks. They had to put it somewhere. What are they going to do if the situation breaks out there? Nobody knows. If it breaks, the purchasers of crude must take the oil. Where are they going to put it? It is a serious situation.

Mr. Mayer says perhaps we are all pessimists. I have always considered myself an optimist, but not in the present situation. Yet, all of us are enough optimists to hope sincerely for the best.

H. L. Doherty.—I have felt greatly discouraged because some men seem to believe that the unit operation of a pool means simply an extension, a little extension geographically. Merely having a pool as a unit does not mean that it can be operated economically. There are not only leases to deal with but separate property owners to deal with, and they can make a great deal of trouble. The courts have decided two or three times that an operator is entitled to the oil that underlies his ground.

There is another point I tried to bring out earlier. We must have learned even here that words can offend people or prejudice them and can have a great effect. I wish I could induce every man who wants to improve the conditions of the oil business not to speak of our present drilling methods as competitive. I hold they are not competitive. They are in the nature of illegal warfare, and the petroleum industry is not seeking anything more than that it shall not be subject to hardships and unfairness, conditions which do not prevail in other industries.

I still make the statement, regardless of what anybody else does, that there is not a single ill of the petroleum business that will not be cured by the unit operation of pools, except those ills which are common to other lines of business and these ills we do not ask any government to cure for us. I think there has been a grievous mistake made on the part of those who tried to use the oil business to bring about a change in the antitrust laws. They will not do it and they are simply going to bring censure on the oil industry.

I doubt whether the oil companies are doing anything illegal that requires a change in those laws. When you say you want to have the right to modify those laws because you cannot stand competition, the man on the street does not understand. If you tell him one property owner can rob the other, he understands this and can understand why we want to change our laws. I would like to get away from the word "competition."

The other point I was going to make is not very important. I was glad to hear some of the other speeches. I have learned a great deal. One of the things I wanted to do was to find out how the men looked on unit operation of pools, and I am afraid from many of the descriptions that in many cases they have not understood what it meant. No engineer, no matter how great he is, can operate a pool and get all the oil out, and do it at the lowest possible cost, without being able to operate his pool as a

unit, but having it as a unit does not alone bring maximum results—brains are also required.

Compulsory or Voluntary Unitization

H. J. Wasson,* New York, N. Y.—I must apologize for not being thoroughly familiar with the early writings on the unitization plan, but is it your program, Mr. Doherty, to have unit operation made compulsory in every case by law; that is, by a federal or state law? As an engineer, I know that unit operation is more economical. I have seen one of the greatest fields in the world (the Mene Grande field) operated under a one-company system in Venezuela, and I am satisfied that it is one of the finest examples of efficient oil production to be found anywhere. For instance, this field produced 15,000,000 bbl. last year with a drilling program held down to four strings of tools. As time goes on we will have more and more similar examples of this irrespective of any help from our lawmakers.

I just want to know, Mr. Doherty, if the plan you advocate comprehends compulsion by the federal or state governments. The engineering phases of this question are one thing, but the relationship which unitization as a compulsory policy would have to basic American principles is quite another matter. A great deal of money has been put into the oil business by well-informed persons who were thoroughly familiar with the rules of the game and could have kept out had they so desired. Now these rules already allow and always have allowed groups to pool their interests or unitize, merge, cooperate, or whatever other word expresses a get-together. Inasmuch as there is nothing to prevent unitization, and as unit operation is in general an economical thing, is it not reasonable to expect that with the dissemination of more accurate knowledge concerning the benefits of cooperative oil production, these matters will work themselves out naturally and without the necessity of making any dangerous experiments in the direction of revising the basic rules?

Were we just starting up the oil business we might conceivably include compulsory unitization as one of the rules. Unfortunately, we are 50 years too late with any change of these rules that, however beneficial to some, could conceivably shove a good many others into the bankruptcy court. This latter is no idle objection, as I am thinking of the man who hits his oil with the last dollar his bankers will loan him; also the fellow even worse off who is down to the same negative financial position and has not yet even found any oil. I maintain that we should let this entire question of unit operation take a natural course; that is, natural with respect to the economic needs of the individuals rather than attempt to attain by law any theoretically perfect harmony with Nature herself.

Dr. George Otis Smith has told us in graphic terms how an oil pool, so far as nature is concerned, is a unit. That is true, of course, and there should be a tendency on the part of industry to work in harmony with this basic fact. Even some pressure could be brought to bear on the industry to adopt this veiwpoint if we had the right sort of machinery for doing it. In my opinion, however, the only workable machinery would be a dictatorship—a just and benevolent one, of course. For example, if we could have a man like Dr. George Otis Smith clothed with adequate power for the proper regulation of the oil industry I, personally, would be very hopeful of the results, as I am sure his sense of fairness and his knowledge of the naturalness of human nature would prevent him from changing the rules too fast merely because of an academic desire to emulate the perfection with which nature may have handled her underground accumulation end of the business.

However, as things are actually constituted, when we start talking about laws to bring this about, we are talking about something that will be given us by the politi-

* Consulting Petroleum Geologist.

cians. If the politicians assay very high in common sense, well and good; if not, who can say where the thing will end and just what sort of a millstone the industry will hang around its neck as soon as it confesses that it cannot run its own business and calls upon the superintelligence of the politicians to save the day.

J. Elmer Thomas says that the industry needs "outside control." If we could locate an omnipotent, all-wise and just being to take over this job, I would agree with him. The raw material actually available, however, for this outside control is, to say the least, somewhat excessively raw; so I say again, let the industry struggle along with its own problems in its own imperfect "unnatural" way, and let well enough alone.

This poor old creaky-jointed machine that we call the oil industry has paid pretty good dividends for a long time, and it would seem no more than prudent for engineers to make a careful and thorough study of such models built on the "outside control" chassis as may be available in other industries before radically changing the design of our own apparatus.

A great many inventions look wonderful while still in the blueprint stage yet fail to make the grade when thrown out in competition with the economic requirements of commerce. This "outside control" idea may have achieved some notable successes outside of the oil business. If so, let us have the facts. Up to the present time the results in coffee, rubber, wheat, etc., give us at least a mild signal suggesting considerably more looking before leaping.

H. L. Doherty.—First I want to call attention to the difficulties of getting a group of properties together. I have tried to do that and have had some trouble with different property owners that forced me to do a lot of drilling I did not need to do, and forced me to operate from wells that produced too much gas and ruined my field. The loss of gas is a very important thing. The shut-off is going to prove a great disappointment because the gas will leak out, the oil will thicken and congeal in the sand.

In the case of drainage and irrigation, laws have been passed to compel the owners to operate as a unit. The whole thing has been adjudicated by law. Even when a man said, "You injure my property by draining," the courts said, "Your remedy is not to hold up and keep your neighbors from being able to utilize their property profitably, but your remedy is by way of damage." All of the common owners must agree how the property shall be operated, and as there is no way of letting one man drill when he sees fit, he must either force you to drill or rob you of your oil and gas.

I do not insist on federal legislation but I say, as I said years ago to the railroads, if you are not prepared to take federal operation and perhaps even seek it, you will find the day when you will have to serve both the state and the federal government. Today the federal government, in my opinion, can legislate as to how oil can be produced without any question as to constitutionality or legality, because it could prevent waste. If the state legislature will legislate to prevent waste I will cease to contend that the federal government be empowered. I think we are better off with the federal government. My opponents say no. Time will tell. I am willing to go on record and take a chance on state laws.

Economic Aspect

W. S. Farish,* Houston, Texas.—I should probably apologize for attempting to discuss Mr. Pogue's paper.[3] I came to listen and to learn the views of others on the present economic trend of the industry, not to attempt to impart my views; but since the chairman has urged me, I am encouraged to state briefly the policy which my own organization is pursuing in the production of oil.

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* President, Humble Oil & Refining Co.

[3] The paper by J. E. Pogue begins on page 405.

I agree with Mr. Pogue's general conclusions. I believe the economic trend to be accurately depicted by him as regards the industry at large. As a producer of oil, however, I am aware of a particular economic trend which I desire to emphasize: *i. e.*, the trend toward unit operation of oil pools.

All engineers are familiar with several factors that trend toward unit operation, such as the necessity to conserve petroleum, to build up adequate reserves, and to recover a larger proportion of our oil, but I believe we fail to realize how large a factor the necessity for lowered costs of production is coming to be in the movement that is forcing the oil producer toward unit operation.

The economic trend is toward lower production costs, and these in turn impel us toward unit operation. In fact, unit operation, in my opinion, offers the only method of reducing costs to a point where we can meet the competition of cheap foreign oil, itself a product of oil pools owned and operated as individual units. We must have low-cost production if we are to survive as producers. Our competitors in Russia, for example, have unitized their producing effort under the direction of the government itself. I am informed that three companies, producing on large concessions in Venezuela, have an acreage cost of about 4 c. per acre, and an average production cost of about 25 c. per barrel. The Dutch East Indies boast some wonderfully rich oil fields operated as units at minimum costs. Persia, in the control of a single operator, has produced astounding volumes of oil per well by reason of an intelligently handled unit operation which has eliminated fully 90 per cent. of the wells that would have followed competitive development, such as is familiar to us, in the same field. Irak, a potentially great petroleum reserve, seems destined to duplicate Persia's record. Colombia and Peru are essentially units in oil production.

All these unit operations in foreign fields mean low costs to our competitors. In many of our competitive fields cost might have been cut in two by the elimination of the hasty drilling of unnecessary wells and the maintenance of gas pressures, which unit operation would have made possible. As producers we must face the facts. Costs of production will be the controlling factor in the economy of the petroleum industry and as producers we must get our costs down or go out of business. I repeat that, in my opinion, the only practical and adequate method of reducing costs of production to the requisite degree is unit producing operations, and I feel that the urge to reduce costs will itself soon become strong enough to force the adoption of unit operation.

But unit operation promises to exert another influence on the economics of the petroleum industry, which is just as important as the matter of reducing costs of production. Unit operation will also solve our problem of overproduction which has plagued us so sorely for the last decade. We have been overproducing crude now for many years. We have talked at length about the effects of it. We have seen our meager profits dwindle, to be replaced by severe losses, periodically. We have debated remedies and argued as to facts, but we have as yet really done almost nothing about it.

We have been advised by some students of the situation to expand our markets for crude in order to relieve this condition of overproduction; but we have already expanded our markets until we have pushed petroleum into competition with other fuels, such as coal, in uses to which liquid fuel should not be put. We are underselling coal, to be sure, but we are getting less than half the value of our fuel oil on a competitive basis. I object to the further expansion of our markets in this direction. Let us use liquid fuel for the superior uses in which it is essential.

Some observers contend that this overproduction is temporary and that the condition will pass away, so that next year, or the year after, it will no longer worry us. A little reflection, however, makes one skeptical on this point. The accomplishment of the geologist and petroleum engineer in finding oil during recent years is too well

known to require any confirmation from me. We have found as much oil in the last 5 years as we did in a generation preceding that period. In another 5 years we seem likely to discover most of our remaining reserves in this country. Must we also produce all of our reserves as fast as we find them?

During the same period in which we have so improved our finding technique, our chemists and refinery engineers have made available to us improved methods by which practically the whole of each barrel of crude has become potential gasoline. Gasoline is the petroleum industry's money crop today, and 70 per cent. of the income which it enjoys comes from this product. Under the circumstances it is just as easy, and there is the same temptation to overproduce gasoline as there is to overproduce crude.

In the face of this critical condition of overproduction of both crude and products, the industry has burdened itself with enormous stocks. We are staggering along with this storage under the old theory that we should carry large storage as insurance against possible shortage in current supply. Storage of crude or products beyond bare working requirements is a millstone around the neck of the company carrying it, today. My associates and I have preached this doctrine for years, and 4 years ago we began systematically the elimination of excess stocks, with the result that our storage has been reduced from 23 to 10 million barrels.

During all this time the industry has failed to develop any effective method of control of flush production. We have not even found an adequate method of attack that is generally recognized. We cannot control our own production of raw materials even today. The Department of the Interior has made helpful suggestions, but only where they wield a big stock, as in some government lands, is there any element of control of flush oil. The industry itself has not even done the things open to it to do. We have failed absolutely to control the production of our raw material and in the final analysis we have only ourselves to blame for the present unsatisfactory state of affairs.

The adoption of unit operation in any considerable number of pools would make possible the effective control of overproduction. When 25 per cent. of our current production comes from unitized pools, distressful overproduction will have ceased. The owners of unit operations will refuse to pour their oil into an already flooded market. They will refuse to accept the inadequate prices which flush oil has always heretofore brought. Instead, they will restrain the flow of their wells until the legitimate demand again overtakes supply. In making this possible, in relieving us of acute overproduction, unit operation offers another advantage equally as important as the lowered production costs it promises.

I have not touched on other important aspects of unit operation, such as the opportunity it affords of building up reserves in the ground—something we have never been able to do in the past in a competitive pool. The subject is too big for this occasion.

It is said that unit operation is contrary to the interest of the small producer. I do not agree. The small producer has most to gain by, and, therefore, should be crying loudest for, some logical policy that will compel unit production rather than competitive production within the individual pool. If I were a small producer (or a large producer either) I would rather own 50 acres in an oil pool controlled on a unit basis than 100 acres in the same pool operated in the usual competitive fashion. The small producer will find, if he will sharpen his pencil, that 5 per cent. interest in a unit operation will be more profitable to him than 10 per cent. of the same pool in a separate leasehold which he must operate individually in competition with other producers, large and small.

Let me emphasize the fact that in the producing branch of the oil industry the unit of competition should be the oil pool and not the individual leasehold or oil well. Nature made the pool, and man made the subdivisions on top of the ground. To

adhere to the man-made boundaries and to ignore nature's work is contrary to the original scheme of things and is fatal to efficient production at minimum cost.

E. OLIVER, Ponca City, Okla.—Have you any suggestion regarding methods of bringing about unit operation?

W. S. FARISH.—My position and the position of my company on this question are matters of record. We believe and we have publicly urged for the last two years that no wildcat wells be drilled until leases have been pooled over the entire prospective area; or at least not until every effort has been made to effect such a pool. I cannot emphasize too strongly the possible good that can come from the adoption of this policy generally. Our lawyers maintain that pooling agreements of this character are legal, even in Texas where antitrust laws are particularly strict. In this policy the industry has a clear field and the chance to benefit itself immensely; it is itself to blame if it does not take advantage of it.

Pooled acreage around all wildcats would result in controlled or unitized production within five years to a degree that would eliminate overproduction and give us a reasonable price for our oil. Flush production would become a thing of the past. Yet we are still not willing to pool acreage in advance of exploration in most cases. We have made some progress, but more often than not we have refused to go to the trouble, or agree to the conditions, that pooling involves.

A majority of the operators in a producing pool—say, 60 per cent., or 70, or 75 per cent. of the owners of the leasehold in the pool—ought to have the right to agree to a program of drilling and production which would control the output of the pool if adopted; and with the approval and under the supervision of the proper state authority such a majority of operators ought to be permitted to put such a program into effect in the pool. In such cases the recalcitrant minority, if one existed, should be forced to abide by the majority decision, administered through the state authority. In Texas, I have gone to some length to try to get authority to pass upon and approve such agreements vested in our conservation officers, the Railroad Commission, but such agreements and control continue to be illegal in that state.

These two devices, pooling in advance of all wildcat drilling, and majority control of producing pools under the direction and with the approval of the state, will give us reasonable control of production in Texas within three years, in my opinion.

J. B. UMPLEBY.—It is interesting to look back over this idea of unit operation. When Henry L. Doherty proposed a few years ago a method of unit operation, the industry was opposed to it. In 1927 Mr. Marland and his committee of nine called a meeting of engineers, in which opinion concerning the role of gas energy in producing oil crystallized. All companies began to watch gas-oil ratios and several conservation commissions became interested in the subject. The latest product of this interest is the Gas Conservation Law of California. In December, 1927, the directors of the American Petroleum Institute declined to recommend unit operation to the industry. One year later they passed a special resolution recommending it. Now it is probably safe to say that the majority of leading executives look upon it with favor.

I think as engineers one of the contributions we can make is to determine as concretely as possible the advantages of unit operation, ways to carry it through, and keep selling these ideas to the industry. The thing is sound from an engineering standpoint and it or something equivalent is coming to be an economic necessity.

Property lines and divisions and competitive drilling and operating are economic suicide, and when everyone comes to realize that, I think we can depend on the brains of the industry to solve the problem of how to consolidate pools.

I noticed that when the Marland and Continental companies wanted to consolidate, they arrived at a value. If that is possible with the holdings those companies have, it is certainly possible in the individual field, if we can get a consensus of opinion among engineers and executives as to the real advantages that will result.

Principles of Unit Operation

By Earl Oliver,* Ponca City, Okla., and J. B. Umpleby,† Oklahoma City, Okla.

(New York Meeting, February, 1930)

It is believed that in connection with the study of unit operation by the Petroleum Division of the A. I. M. E. a review of the simple principles of unit operation would be helpful. To that end, the following discussion is submitted. It is not to be considered in any sense as the conclusion of the committee, but rather as material submitted for its consideration and represents at this time only the viewpoints of its authors.

Growth of the Oil Industry

In 70 years the oil industry has grown from a single well on Oil Creek, Venango County, Pennsylvania, producing 25 bbl. per day, to more than 400,000 wells scattered over five continents with a daily output of 4,000,000 bbl. In that time petroleum has expanded from its simple use as a medicine in a few localities to a multitude of diverse uses in homes of every country the world over. During those years the oil fields of the United States have produced two-thirds of the world's output and have shipped their excess production into almost every country.

In those years several hundred thousand good wells in the United States declined into small ones and depleted shallow deposits gave way to deep zones; so that the United States crude oil industry gradually changed from one of low cost production to one of higher cost. Throughout its entire life it has labored under two serious economic disadvantages, namely, constantly recurring periods of demoralization through overproduction, and competitive development methods that are wasteful.

Development of Foreign Competition

During the transition from low to higher cost production in the United States, events even more significant were taking place in foreign lands. Jungles were tamed and deserts conquered. Oil deposits were found and developed until, in the words of Sir John Cadman, "the globe is now drenched with a commodity which, although necessary to life, involves but an irregular and sometimes meager expenditure of life in its

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† Chairman, Petroleum Division, A. I. M. E.

primary production." These are low-cost foreign deposits demanding their share of the world's markets.

As a consequence the United States petroleum industry now finds itself "sending coals to Newcastle." A barrel of high production-cost oil from Texas meets in London a barrel of low production-cost oil from Persia; one from Los Angeles meets in Tokyo another from the Dutch East Indies; even in New York one from Tulsa meets one from Maracaibo—with the inevitable result that occurs in every case where a high production-cost product is met in competition by one of low production cost.

Other matters being equal, the profitable trade territory of a product extends only so far from the point of origin as the production cost at the point of origin plus transportation cost equal those of a like product to the same point from a competitive region. On this basis the United States petroleum industry is finding its profitable trade territory more and more circumscribed. This tendency will increase rather than decrease during the years immediately ahead as foreign fields are opened. At the same time the United States fields continue to pile up potential overproduction at an unprecedented rate.

Method of Meeting Competition

Thus we have an entirely new set of conditions that face the United States petroleum industry. Two differences stand out. In former years there were no vast proven reserves piled up behind the overproduction. Neither were there foreign competitors who could produce vast quantities of oil at much lower cost. These two new conditions call for specific remedies. First, output of United States pools must be curtailed to an amount sufficient to supply only their profitable trade territory. Second, United States production costs must be lowered in order that the profitable trade territory shall be maintained at a maximum. Finally, some character of government relief might become necessary; but that help would naturally follow, not precede, application of relief measures already available.

The Federal Government, the American Petroleum Institute, and many individuals within the industry, having foreseen the conditions that are described, have attempted to formulate remedies that will bring about the results above set forth. Prorations and shutdowns are being utilized, but these are nowhere regarded as more than temporary expedients. They are difficult to enforce and do not eliminate waste, which is so necessary to reduce costs. Without exception the many studies that have been made have resulted in the conclusion that general adoption of what has now come to be known as unit operation offers most promise as a first step in bringing about the objects sought.

UNIT OPERATION

The term as it is being used in the industry has not yet reached an exact definition but in general it implies that all properties in the respective oil and gas pool shall be consolidated into a single operating unit in some manner that will eliminate the competitive drilling-drainage

FIG. 1.—MAP OF WORLD SHOWING OIL FIELDS WITH EXCESS CRUDE OIL (SEE SOLID CIRCLES) AND IMPORTANT MARKETS FORMERLY SUPPLIED BY AMERICAN OILS THAT ARE NOW BEING GRADUALLY SHARED BY LOWER COST FOREIGN OILS (SEE HATCHED CIRCLES).

feature in its development and operation, and will permit of utilizing to a maximum forces of expulsion native to the reservoir.

In the typical virgin pool natural gas, oil and water are found confined together under high pressure, each occupying its respective place in the reservoir. In many cases this pressure is sufficient, if controlled and

directed, to expel a large percentage of the oil content from the reservoir via flowing wells without the use of other equipment. It is obvious that most efficient oil recovery is effected if escape for any of these fluids in the reservoir is permitted only through holes drilled into the oil zone, since in that event neither gas nor water could escape without driving oil

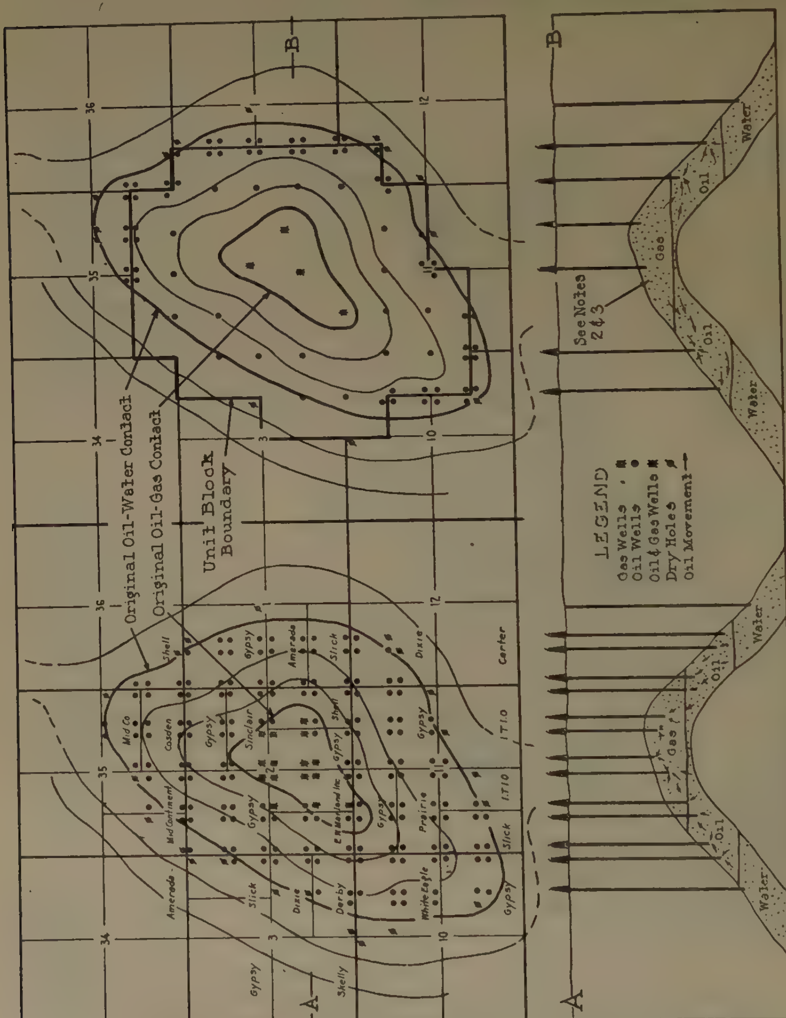

Fig. 2.—Hypothetical example: *A*, competitive development; *B*, unit development.
(1) Line *A-B* in upper plate is shown in cross-section below.
(2) Under unit operation gas wells are closed in.
(3) Under ideal unit operation as gas is being removed from the reservoir with the oil through the oil wells it would also be forced back into the gas-sand through gas wells to maintain the reservoir pressure.

ahead through the reservoir rock to the point of escape. That procedure would be followed in unit operation.

Competitive Extraction Promotes Incomplete Recovery

Under the competitive drilling system, however, the location of wells is determined by surface boundaries, not by reservoir content. Each

land owner is permitted to drill as many wells on his own land into the common reservoir as he desires and is entitled to all oil and gas he can draw out through those wells. If he drills into a gas zone he draws off gas, thus reducing the reservoir pressure without utilizing it to assist in the work of oil recovery. Oil in the reservoir rock is thus robbed of force that would otherwise move it to the well. For this and other reasons to be considered, oil extraction under competitive drainage is sometimes as low as 10 per cent., leaving 90 per cent. lost to recovery, notwithstanding there might have been sufficient energy stored in the reservoir originally to bring about several times the recovery if it had been efficiently controlled. This energy cannot be so controlled under competitive extraction.

Two other factors contribute to low recovery under competitive extraction. When pressure is reduced, as it must be under that method, oil becomes more viscous through loss of absorbed gas, and, as a result, becomes more difficult to move through minute pores of the reservoir rock. Therefore dissipating gas from an oil sand lessens the propulsive force and increases the need for it. Also, when the gas-sand portion of the reservoir becomes emptied of its gas content, oil migrates into that portion and is lost to recovery on account of adherence to sand previously unsaturated with oil. Under unit operation as pressure becomes lowered gas would be reintroduced into the dry gas-sand portion in order to maintain pressure.

Competitive Extraction Increases Developing and Operating Costs

Under competitive development many more wells are drilled than are necessary for the economic extraction of the products from the reservoir. Frenzied, costly development takes place, bringing about sharp peak loads the handling of which requires extensive facilities over a short period. These are hastily planned and soon operating only to a small part of their capacity. Pipe lines are notable examples. Expensive surface storage is built. Irregular labor conditions are promoted. Harmful social conditions result.

Competitive Extraction Promotes Overproduction

Unrestrained competitive extraction from an oil pool is not only responsible for vastly reduced recovery, inadequate gas utilization, and increased cost of development and operation, but in addition it is largely responsible for another serious evil in the United States petroleum industry; namely, overproduction with its demoralizing market conditions.

Oil and gas tend to flow from all points in the reservoir toward the point of lowest pressure. The owner who so develops and operates his property as to induce gas and oil to flow from the land of another into

his own land and escape through his own wells, is operating entirely within his legal right and in harmony with long established practices of the industry. Consequently, in competitive development, the rules of the chase supplant the customary rules and stabilizing influences of industry. The necessities of capture interfere with free operation of the law of supply and demand.

Production should increase quickly in response to increased price and decrease with equal facility in response to decrease in price. This can occur only when competitive extraction is absent. For that reason, the individual pool is the natural competitive unit. Its products compete in the market place with products from other pools. Distinction should be made between competition in sale and competition in extraction. The first affords that protection to the consumer which is necessary; whereas, the second in no wise protects the consumer, but it demoralizes the industry.

Examples of Both Methods

As more or less typical examples of the two methods of control, two pools are described. One is a small American pool with divided land holdings. The other is a foreign pool that is being operated as a unit.

In the American pool two-thirds of the total area contained gas only, while one-third contained oil. The reservoir rock was sand, fine but regular in texture, and continuous throughout both the gas and oil portions of the reservoir, with freedom of movement between them. The pool was discovered and drilled some 10 years ago in the competitive manner that characterizes United States oil field development. The gas was depleted rapidly through gas wells, leaving the oil to be produced more slowly. Recently several complete cores were taken from the oil sand. Laboratory examination of these cores disclosed that 94 per cent. of the original oil content yet remained in the reservoir rock, with expectation that 90 per cent. will remain when the wells cease producing. The total amount of oil to be extracted under these conditions will be approximately 12,000,000 bbl., leaving somewhat over 100,000,000 bbl. in the sand practically lost to recovery. Sufficient gas was stored under pressure in that reservoir to drive out much of the 100,000,000 bbl. that remains if it had been conserved and so utilized.

In striking contrast with this method of development is the famous Masjid-i-Suleiman (Temple of Solomon) field in Persia. It is 20 miles long by 4 miles wide, operated as one unit. It was opened in 1912. The reservoir rock is a steeply folded cavernous dolomitized limestone, 900 ft. thick. As in the American pool, gas was found on top of the structure but the gas wells were closed in and the gas is permitted to escape only through the wells drilled into the oil zone. It thus drives oil ahead through pores of the reservoir rock to the point where pressure

is relieved by an oil well. The wells averaged 8000 bbl. per day initial and continue large up to the time they show an excess amount of gas by virtue of the gas-oil level in the reservoir becoming lowered. Then they are closed in and wells lower on the structure are opened.

The potential daily output of the pool is greatly in excess of that which is utilized, although only a small number of wells have been drilled on this large structure in comparison with characteristic development in the United States. The pool has produced 300,000,000 bbl. of oil and has many years proven reserves at the present rate of extraction. The oil wells have flowed, and continue to flow, their production at all times, as the owners express "with no more trouble than opening a tap to draw water for the bath." Very complete recovery from the reservoir rock is being made in this pool by the unit type of development. It will be noted that in this pool oil wells are permitted to flow until they change to gas wells, whereas under competitive development gas wells are permitted to flow until they change to oil wells.

In the Persian pool oil and gas zones are both owned by the same interest, whereas in the American pool above described some operators owned only gas while others owned oil. Under the competitive drainage system no method has been evolved whereby the gas-well owner is compensated for deferring extraction of his gas. That, under competitive development, would be difficult to adjust, whereas under unit operation no such problem arises.

These two pools illustrate the comparative disadvantages under which the United States petroleum industry with its competitive extraction methods is competing in world markets with the output of foreign fields. They are not offered as strictly parallel cases. Reservoir conditions differ; but much American oil is being produced, and has been produced, under conditions closely comparable to the American pool above described, whereas a greater part of foreign oil is produced from large blocks with the competitive development feature either absent or very materially reduced.

Compulsory Versus Voluntary Unitization

Most students of the industry are in agreement that the consumer, the individual operator, the individual royalty owner, and the general public, as well as the labor employed would, each and all, be greatly benefited if individual oil pools were operated as units; but general adoption of the practice in the United States has been delayed because information as to its advantages has been lacking and satisfactory means have not been developed to bring about consolidation.

Unanimous agreement on details of consolidation by parties entitled to drill into a common pool is so difficult to procure and yet unanimous action is so desirable in unit operation that advocates of legislation to

enforce unit operation have not been lacking. However, taking one property from an individual and arbitrarily substituting another therefor without his consent is a procedure difficult to contrive under American law, even if it is obvious that consolidation would be in the public interest and is being done at the request of a majority interested in the single pool. This is true notwithstanding it may be apparent that the one who refuses to cooperate is prompted solely by the hope of extracting more of the products from the common pool than underlie his own land.

The danger is that if the industry does not aggressively undertake those things within its control, operators, seeking relief from present conditions and being unable or unwilling to await the slower processes of constructive action through their own efforts, will appeal to government for help and burden the industry with legislative enactments depriving it of that freedom of action it now enjoys and can retain if it shows a disposition to correct its own problems. The movement should be gradual and flexible so that mistakes may be eliminated as each step leads to the next one.

When the complications of compulsory unitization are faced, voluntary unitization, by comparison, appears simple. It is altogether in harmony with American conceptions of property rights, but its successful and general adoption is dependent upon a more widespread understanding of the issues involved.

To assist in bringing about that understanding is the basis on which the American Institute of Mining and Metallurgical Engineers is justified in making this general study of unit operation. With its international membership it has long been a forum for the discussion of engineering methods that may be developed to the common good. Its established position and the character of its personnel should help to inspire confidence in its findings and recommendations. Leaders of the petroleum industry entrusted with the duty of bringing about stabilization have invited it to help in that undertaking and to assist in compiling information. A handbook on unit operation is being prepared by the Mid-Continent Oil and Gas Association, to which this Division is asked to make contributions of material.

When the consuming public, the oil producer, the royalty owner, and the officials of government—legislative, judicial and executive—all understand more clearly the issues at stake, and the machinery and methods of consolidation are such as enlist the confidence of all these parties, it is to be expected less difficulty will be found in enlisting cooperation. "There is nothing on earth more powerful than an idea when its hour has come."

As an ultimate ideal all the competing ownerships that will drain from the common reservoir should consolidate into a single blanket ownership—the competing leases into a blanket lease and the competing royal-

ties into a blanket royalty—all of which would be entitled to a like percentage in kind of the product extracted from the pool as the individual property contributes in value to the aggregate value of the unit. The purpose of the consolidation would be more economic extraction and better adaptation to the law of supply and demand. One hundred per cent. consolidation, however, could be expected only as the result of many and protracted efforts. Fifty per cent., sixty per cent., and seventy per cent. consolidations with machinery that would enable ready acceptances of the remaining percentage if, as, and when they become desirous of joining the consolidation, should be regarded as satisfactory progress in the early stages of the movement.

While there are no means by which an individual may be required to join a unitization project, yet there is adequate precedent, and also justification, for restraining him from operating his property so as to injure the property of his neighbor. If that principle were strictly imposed, much of the advantage would be taken from the operator who will not join his neighbors in unit operation. He who insists upon his pound of flesh should have it, but he should be required to exercise care in taking it. Under those circumstances, unit operation would be as desirable to him as to his cooperating neighbor. The law of oil and gas was influenced in its development by analogy with the law of wild animals. Like wild animals, they must be captured before ownership in them becomes vested. However, to protect wild animals from wasteful slaughter and final extinction, as well as to equalize opportunities to acquire them, specific regulations covering their taking are imposed by law upon the hunter. Unless operators privileged to drill into a common pool and extract the products therefrom can agree with each other as to the rules of capture, the State may be compelled to impose laws, of capture as it has done for wild animals. The alternative to this unwelcome condition is voluntary agreement between the owners.

Parties to be Benefited

The parties who would be benefited by the general adoption of unit operation and the manner in which they would be benefited are given below. The advantages are too numerous to permit individual comment. They can only be listed with a few general remarks. Perhaps the most widespread erroneous conception regarding unit operation is that it is monopolistic in tendency and will eliminate the small company and individual operator. As a matter of fact its influence would be the exact reverse of that indicated.

Competitive drainage makes vast aggregations of capital necessary in one organization in order to reach out constantly from point to point for a crude supply. If, however, methods of development become such that compact deposits of crude can be proved and made available to be

drawn upon as needed over a period of years, small refining and marketing companies owning or holding interests in one or more such units will have little necessity, and therefore less tendency, to consolidate with others. Many complete small organizations will be developed rather than a few vast ones. Unit operation will, of course, be likewise advantageous to the large companies in that it will also give them dependable crude supplies; but it will remove much of the incentive for the large companies to consolidate with other large companies and become still larger. It is desirable to the large company as it is to the small company, but not nearly so necessary.

Neither will unit operation mean the passing of the small producer. An interest in a small unit that an individual operates for himself and a few partners gives to the small producer an opportunity to survive that he cannot possibly have if he attempts to compete under the old wasteful competitive type of development to which he is accustomed. His survival is dependent upon adjusting himself to new conditions.

General adoption of unit operation would give to each party the following advantages:

Consumer

1. Greater assurance of permanent and stabilized supply.
2. Receipt of products over a period of years at lower average price.
3. Greater assurance of freedom from monopolistic control.

Producer

1. Less capital investment required.
2. Lower development cost.
3. Lower operating cost.
4. Products would be made more responsive to the producer's needs.
5. Increased acre oil yield.
6. Increased gas value.
7. Stabilized business.
8. An investment more readily salable.
9. More actual control over his business.
10. More dependable crude supply for the other branches of his business.
11. Saving on plant capacity.
12. Saving on pipe lines and storage tanks.

Royalty owner

1. Stabilized crude price structure.
2. Increased acre yield.
3. Increased gas income value.
4. Stabilized business and stabilized income.
5. Reduced risk.
6. An interest more readily salable.
7. A property that is better collateral.

General public welfare

1. A great industry better stabilized.
2. Stabilized labor conditions in the industry.

3. Permanent neighborhood industries on account of steady gas-fuel supply.
4. Permanent communities.
5. An assured domestic oil supply for national defense.
6. A longer period of dependable domestic oil supply for commercial and industrial purposes.
7. Reduced speculative spirit.
8. Reduced necessity for vast oil organizations.
9. Reduced monopolistic tendencies.
10. Goverment freed from need of supervising the oil business.
11. Increased opportunity for small complete businesses.

Objections to Unit Operation

Objections urged against unit operation generally fall within the three following classifications:

1. Fear that it violates antitrust laws.
2. Contention that it reduces personal control of property.
3. Fear that it would delay income from property.

A better understanding of unit operation is causing the first objection to disappear. One single unit produces much less oil than the average large company controls. If these units are operated independently of each other there will be real but not destructive competition. The law of supply and demand can then operate, which it cannot do under competitive extraction. If, however, a great number of these units are tied together by interlocking directorates to the extent that, in effect, they would be under one control, justification would exist for the fear of antitrust law violation; but a condition of interlocking directorates between the units is quite another matter than the one under consideration. It has no inherent connection with unit operation. It can and should be avoided.

The second objection is more in form than in substance. Competitive drainage methods permit the superintendent of the company that owns the individual 80-acre tract to determine a few relatively unimportant matters about operating the tract, such as the character of roads he shall build or the type of boilers or rigs he shall use, but it does not permit him to determine when and how many wells he shall drill, how much oil he shall produce, and when he shall produce it. These more important matters are determined by that operator in the pool with least vision. All others drawing from the common reservoir must accommodate their pace to the one he sets. Under unit operation each participating owner would have a vote in determining these matters of most importance. The best judgment of the pool would prevail in the common councils as against the poorest judgment, operating alone, under the competitive drainage system.

The third objection would be subject to determination and could be provided for in the consolidation agreement. Some owners would prefer

to delay extraction to satisfy later needs, or for better market conditions, whereas others would prefer immediate extraction. Trading arrangements could be made among stockholders in a unit operation that would enable the desires of each to be taken care of in accordance with his daily or monthly needs, provided of course such trading arrangements came within the accepted proved reserve estimate.

The greatest deterrent to the adoption of unit operation is the customary reluctance human beings experience in breaking away from old habits and practices and adopting new ones. Individuals can do that as individuals, but difficulty is encountered in persuading a great number of individuals to do it at one and the same time. No serious objection to unit operation has been found but it requires a degree of concerted action difficult to obtain. The rapidity of its general adoption will depend upon educational processes and economic pressure.

Method of Unitization

This study has discovered a definite trend toward unitization with much sympathy for it and many embryonic units already in existence, but their developments have not progressed to the point where results that show their full significance can be tabulated. Neither has the movement progressed to the point where any single method of unitization has been evolved that is accepted even by its authors as the one correct method to bring about unit operation. Each attempt is admittedly imperfect and incomplete and represents an independent experimental groping toward, rather than an arrival at, the method which will serve as a standard for future efforts. This is said notwithstanding each of these attempts is much in advance of the unorganized competitive style of development, and many already show substantial economic rewards.

While no complete unitization system that may be used as a standard has been discovered by the search made in this study, yet certain principles have been suggested that appear worthy of consideration, and which if observed might smooth the way to more rapid adoption of unit operation. Further experience might prove many of these impracticable but they are believed to reflect the present major sentiment on the movement. These observations are as follows:

General

1. The movement should be promoted through education and persuasion rather than through direct compulsion, but on the other hand those who persist in operating their properties on a competitive extraction basis might well be restrained from so operating them as to interfere with the proper and reasonable rights of other operators who are privileged to drill into the common reservoir.

2. The program of education should be designed to reach not the producer alone, but also the royalty owner, the consumer, the general public, and Government officials

—executive, legislative, and judicial—to the end that there will be developed an intelligent, well-informed public opinion.

3. Judicially defined correlative rights between owners privileged to extract products from a common reservoir should be reviewed by courts in light of late scientific knowledge respecting the relationship and function of oil, gas and water in the common reservoir, in order that the injury any one operator can do all others by his method of taking might be more clearly defined and his duty determined.

Specific—for each project

1. The ultimate ideal would be that the competing ownerships that will drain from the common reservoir should be consolidated into a single blanket ownership—the leases into a blanket lease and the royalties into a blanket royalty, but early efforts can be no more than approaches toward that ideal.

2. The consolidations should be made on an appraisal basis, but provision might be made for later adjustments if immediate determination of final ratios were found impossible.

3. The management should be democratic in form with minorities protected by right of appeal.

4. Each unitization project should be specially designed to suit the peculiar needs of the case in hand rather than attempt to apply some standard method developed elsewhere.

5. Initiation of a unitization project should be through progressive steps with complete freedom of acceptance or rejection on the part of any owner until after the picture is set up and each owner knows the relative rate of exchange for his property and the character of management under which the unit will be operated.

6. The consolidation should be a continuing process, including in the beginning those who are ready, but making provision whereby additional owners in the common pool may be accepted when, if, and as they are ready, with rate of exchange, of course, being adjusted to relative values as of date of exchange.

7. Very general principles only should be included in the contract setting up the unit, but it should make provision for a continuing board of directors with wide discretionary powers.

8. Products in proportion to shares held should be delivered to the respective share owners at cost with flexible arrangement permitting each owner to take products if, as, and when needed, within proper margin of safety.

. . . .

In any attempt to summarize the status of unit operation one would naturally like to give credit to those responsible for bringing the movement to its present position. However, controversy over methods of application that characterized the movement in its early stages, as distinguished from constructive discussion, has not yet completely disappeared. So long as that condition exists there can be no proper evaluation of the relative influences various individuals have exercised on that movement. For that reason the authors reluctantly defer any discussion of that aspect, leaving it for some later historian to evaluate.

[For discussion of this paper, see page 88.]

Some Development and Operating Economies of Unit Operation

By Sam Harlan,* Bartlesville, Okla.

(New York Meeting, February, 1930)

At intervals during the past several years the oil industry has been confronted with the problem of forestalling crises in its affairs. These crises have been reduced to periods of depression which, fortunately, the industry has been able to survive. Under the existing competitive practices which control the producing division of the industry it apparently has been proved that the best efforts logically to curtail development and producing operations are inadequate for effecting a true production balance and the consequent stabilization of prices. The industry is awakening to the fact that the situation warrants revolutionary thought and at this time it is looking for a permanent solution of its problem in a general plan for unit development and operation such as the one first proposed by Henry L. Doherty. Mr. Doherty's proposal was designed not only as a means for stabilizing the industry as a whole, but its principles involve very definite potential benefits for the average individual operator and royalty owner as participants in pooled projects. The benefits to these individuals would be derived from maximum recovery, the maximum utilization of natural energies, the minimization of development and operating costs, enhanced values of leases and royalties through improved efficiencies and ultimate yields, improved earnings through stabilized crude oil prices, etc. This plan was revolutionary to the industry's practices and at the time was rejected, but it now appears that the development and operating policies for new properties are continually approaching the ideal of the original plan.

Oil companies are constantly extending their efforts to improve all factors that have a bearing on the costs and efficiencies of their operations. These efforts may, in some degree, be a normal outgrowth of the industry's progress, but the forced consideration of market conditions, the growing appreciation of the importance of regulating operations for maximum ultimate economies and the depreciation of the old principle of maximum flush at any cost, come from a new school of thought which has been stimulated by the immediate pressure of overproduction and

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an insecure ultimate margin of profit. These evolutionary and forced policy alterations, as they exist, do not represent the oil production business as being greatly influenced by the utmost that can be attained from cooperation and resourcefulness.

At the present time the potential future earning power of the oil industry has assumed a decidedly unhealthy aspect because of the inability to foresee or at least to rectify the conditions in production and competitive operations that have been brought about by the failure to apply the proper cooperative measures in new operations. The industry has gone on record as acknowledging this weakness in its economic structure and has sponsored, through its organizations, certain corrective plans which, as stated in the first paragraph, relate to unitization.

An important step toward true unit operation, as advocated by Mr. Doherty, has been the rather general effort to pool ownerships and to develop and operate groups of leases and entire pools of varied ownership under single management. There are a number of such projects in the producing fields of the United States and there is little doubt but that this phase of the Doherty plan will be more extensively applied if the tangible benefits prove to be as impressive as exponents of the principle anticipate.

It is the object of this paper to disclose the savings that have been realized from the development and operation of a typical "unit" comprised of a group of leases covering an entire pool under single management. For this purpose a property has been chosen that is generally representative of many Mid-Continent pools and on which complete cost data are available. The reflection on production of single management and an orderly development will be considered only in a secondary sense, inasmuch as that portion of the history is only partly written.

General

The Haverhill pool of the Empire Oil Refining Co., situated approximately 11 miles south of the El Dorado field in Butler County, Kansas, has definitely brought out many of the economies that can be effected through the single management of a group of leases. The unusual benefits that have been and will continue to be accrued have been made possible by Empire's 100 per cent. ownership of the property and the desire of that company to develop and operate the project in such an orderly and economical manner that all costs and efficiencies might permanently be influenced as favorably as the control of all pertinent factors will permit. By observing an orderly and systematic drilling and development program, many definite benefits have been derived that would not have been available had the area been controlled by a

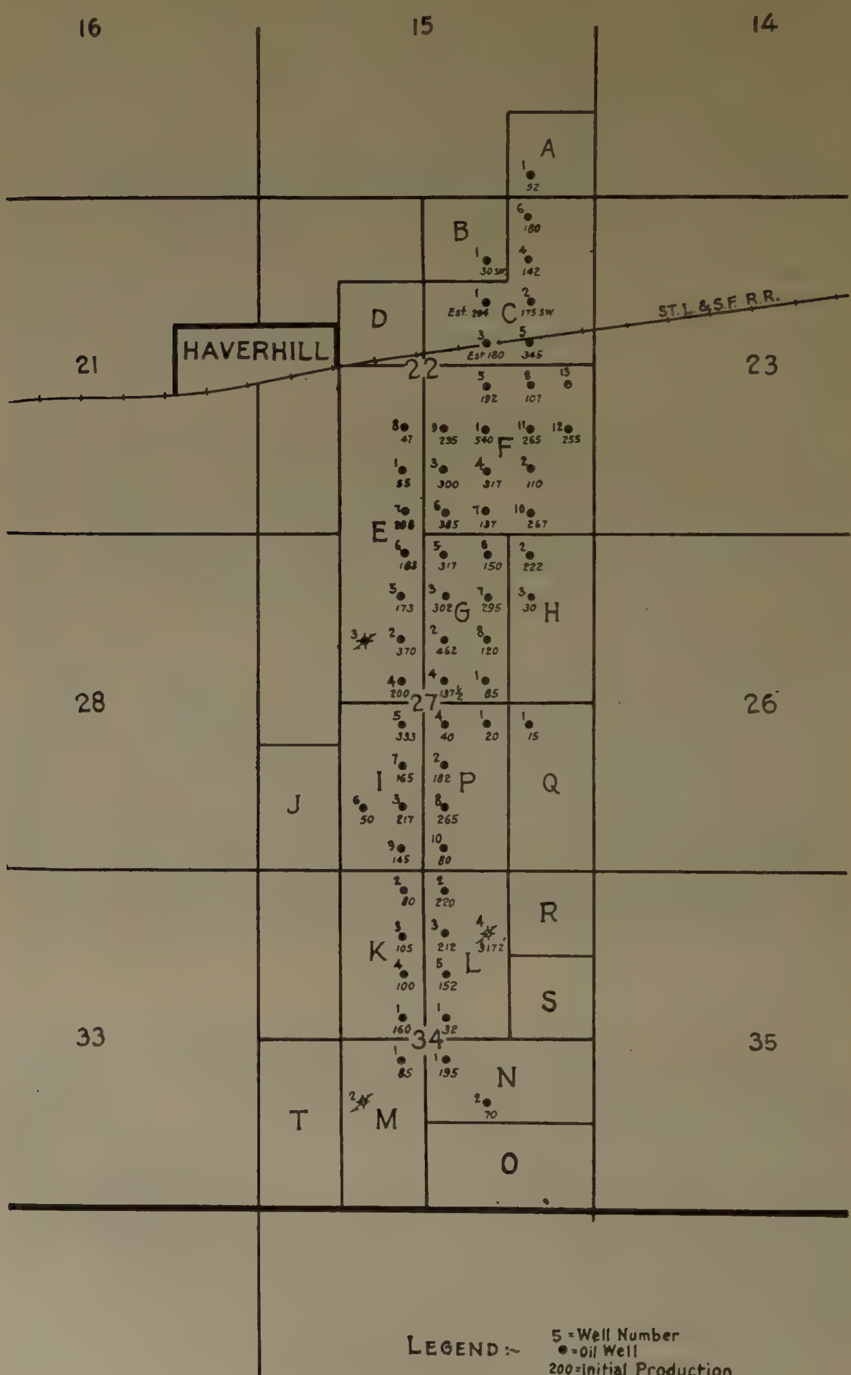

FIG. 1.—HAVERHILL POOL UNIT, BUTLER COUNTY, KANSAS.

varied ownership, or had Empire's leases been interspersed by foreign properties and the pool completed in the usual competitive manner.

Fig. 1 shows the productive Haverhill area. It comprises some 800 acres and the oil pay is Bartlesville sand occurring in the characteristic trend formation at a depth of approximately 2750 ft. The pool has been developed on the basis of one well to 10 acres and is 24 locations in length and an average of 3 in width. The general limits of the productive area were fairly well defined in the early stage of development, thereby enabling the company to adopt a definite drilling program. The average of four strings of tools and the maximum of seven have been employed over a period of 32 months in drilling the area. Fifty-nine oil wells and three dry holes have been completed, one well is drilling (Jan. 20, 1930) and it is probable that at least four others will be authorized before the property is considered as being fully developed. There are 14 producing leases.

Effects of Single Ownership on Development Costs

For comparative purposes, the Haverhill development expense has been checked against two Osage properties on which the total of 32 wells were drilled with as many strings of tools and in record time. These two properties approach the extremes in drilling policies for proved productive acreage under single management. The Osage wells had the same general characteristics as those at Haverhill. The total development cost per average hole drilled on the former was $52,200, while the corresponding expense for Haverhill was $30,222. The expense of complete strings of big pipe and rigs for each well, the purchase of unduly large capacity equipment that would safely care for maximum anticipated flush production, the expense of installing individual gas engines and standard ends, when central powers would have sufficed, the accumulated penalties for untempered haste, etc., apparently can go to make up a penalty in excess of 50 per cent. of the corresponding cost for the same property if drilled up and equipped in a conservative manner. Such penalties occasionally may be justified in extremely competitive areas which yield compensative flush.

It is not desired to compare the cost of developing the Haverhill block with properties of the opposite extreme; the comparison that has been made was merely to set forth the possible margin of waste that may arise from aggressive development.

The total cost of developing the Haverhill block has been less than was anticipated. Savings that have been realized through unitized operations are apparent but some are of the type that cannot be accurately measured. In analyzing these various factors, their tangible importance, in some cases, must be estimated. Where such assumptions were necessary, an effort was made to employ conservative values.

Dry Holes Saved

If the leases had been interspersed by foreign properties or if the leases as they are had been of varied ownership, competitive drilling would have forced a number of wells that would have been uncommercial or dry. By a gradual development and giving attention to offset requirements, it appears that the equivalent of 14 dry holes has been saved. This seemingly large number of failures would be justified by the narrowness of the commercially productive trend, the relatively large number of leases involved and the relatively low recovery from edge wells.

Estimated net savings from 14 less equivalent dry holes, $252,000.

Savings in Drilling Expense

The pool has been developed with the maximum of seven strings of tools running simultaneously. Rigs, big pipe, flow tanks, water and gas piping, etc., have been manipulated in such a manner that only seven complete rig outfits and only five complete strings of big pipe, being, 20, 15½, 12½ and 10 in., have been issued to the entire pool. With normal competitive drilling, it is probable that at least 16 complete drilling units would have been required.

Estimated savings, as the difference between the total depreciation and handling costs of the two layouts, $63,000.

Savings in Lease Tankage and Pipe Line Systems

If the pool had been drilled with the average of 12 strings of tools rather than with four, the peak production would have been approximately 7500 bbl. per day rather than 2400. This volume of oil would have required the equivalent of a 4-in. outlet rather than the 3-in. that serves the pool. Greater lease tank capacity also would have been required.

Estimated net cost of added pipe line capacity $13,500 and lease tankage $10,000.

Benefits from Purchase Discounts and Standardization

In being able to foresee the equipment requirements of a unit project, the ultimate can be attained in benefits from equipment standardization and purchase discounts. Savings from these factors are largely of potential value, depending to a great extent on an organization's rating and personnel. In employing standardization principles, the expense of replacement parts and carrying an excess of surplus equipment stock is minimized.

Benefits to Haverhill from this source, $28,000.

Savings in Dwellings and Buildings

If the Haverhill leases had been drilled rapidly, there now would be a surplus of houses and buildings after the flush period.

Estimated net savings from this source, $8,000.

Savings in Individual Pumping Equipment

In centralized operations, maximum benefits can be derived from central pumping powers. With subdivided ownership, arrangements occasionally are made among the various operators for centralized pumping, but such arrangements are seldom as satisfactory as company-owned pumping units. For this reason it is the usual practice for each operator to install his own powers, even though his property comprises as little as 80 acres. Unless the pool could be efficiently unitized and equipment properly laid out, a number of wells could not be pumped by jack without having a surplus of central power capacity. In this connection, it is of interest that all Haverhill wells are on jack operation from four central powers, which is the average of 15 wells or approximately 160 acres to the unit. Based on past experiences on other similar leases that were segregated, the Empire company is confident that if there had been the ordinary interference from outside ownership that instead of a 100 per cent. jack and power operation there might logically be 10 individual pumpers at edge locations. This paper neglects probable investment savings, as a benefit from unitization, in central powers.

Estimated net savings in equipment depreciation differences between 10 jack wells and 10 beam wells, $28,000.

In the development of average properties, 80 to 160 acres each, it is the customary practice to finish all wells with individual pumping equipment and then to change over to central pumping after the completion of all drilling operations. This procedure requires that standard ends, prime movers, etc., be furnished for each well prior to their being equipped with pumping jacks. This expense can seldom be completely eliminated but where methodical development is observed and the general limits of the commercially productive area are defined at an early period it is feasible to have central powers in place prior to complete development. Twenty-one Haverhill wells were finished with jack equipment at an average net saving of $2800 each.

Total savings, $58,800.

Savings in Water and Gas Systems

With rapid development, the gas and water systems would have been considerably more extensive and of greater capacity than has been necessary under actual conditions.

Savings as the difference between the ultimate depreciation of the two systems, $15,000.

Miscellaneous Development Economies

An orderly development has made it possible to secure maximum benefits from studying sand, water and general development conditions. The water table around the edge of the pool has been found to be variable. By careful correlation work the hazard of drilling into bottom water and the expense of plugging back has been minimized. Extensive coring and studying sand conditions have been a valuable guide in spacing shots and liners. Without development as a unit property and the resultant studies that have been made of sand conditions, it is doubtful that complete information would have been secured pertaining to the extent of dry and oil-bearing zones in the oil pay and to the source and extent of bottom water. The development at Haverhill of the graveling principle has saved as much as four weeks' clean-out and tool work in the process of completing some of the wells. This principle involves cleaning out cavey wells, packing the shot holes with igneous river gravel of uniform size and then running a liner through the gravel. It is doubtful that this idea would have been perfected if a number of operators had been involved with a few wells each.

Total estimated savings in tool work, $9000.

Economies Effected in Financing Expenses

If a $2,000,000 development project, as Haverhill, should be unforeseen and not provided for in the normal budget, and if rapid development were forced, a supplemental appropriation would be necessary. Such unforeseen financing imposes a strain on an organization and may be expected to cost twice as much as normally.

There is a tangible economy in keeping cash requirements to the minimum. Interest at 8 per cent. is chargeable against unredeemed cash expenditures. This interest charge on the difference between the cash outlay as the result from having an average of 12 drilling strings in operation rather than the actual of four, together with other cash difference in equipment expenditures, amounts to approximately $26,000.

As developed, Haverhill has nearly $245,000 less capital investment than would have been set up had there been normally aggressive drilling. Interest and carrying charges on this total investment saving at the rate of 10 per cent. for the first year and on the unsalvaged portion over the remaining life of the property represents a net saving, totaling approximately $81,000, in favor of the unit plan.

Savings in Operating Expenses from Single Ownership

A concrete comparison of cost records of the unitized Haverhill property with six similar segregated nonflowing Bartlesville sand leases which average 11 wells each and which are pumped from central powers has revealed that for the first three years the lifting expense at

Haverhill will be less by the amount of $92 per average well month or the total of $212,000. Over the life of this property, operating benefits will total more than $284,000.

The actual and anticipated savings in operations are dependent on many factors. The centralization of properties is an incentive to the development of improved operating practices. An example of such benefits is the discovery at Haverhill of the value of graveling cavey shot holes. The average saving of $30 per well month in maintenance costs and approximately 8 per cent. production outage is being realized from the average graveled well in that area.

Centralized activities permit operating with minimum labor, transportation, lease stock and miscellaneous expenses.

Properties equipped with properly designed and economically operated and maintained equipment cost less to produce. Hastily developed leases ordinarily do not reap maximum benefits from this potential economy.

By producing all wells from efficiently operated central power units, the added expense from a few beam wells has been eliminated. It has been determined that beam wells of the Haverhill type each cost approximately $52 more per month for operation and maintenance than do jack wells.

There has been a saving from the minimization of the volume of water lifted with the oil, greater than would have been possible had the leases been segregated.

All of the above, and undoubtedly many other factors, contribute to the estimated ultimate $284,000 enhancement to Haverhill, through efficiencies directly and indirectly creditable to single ownership and management.

Production

This paper will not attempt to set a value on the effect on production of having Haverhill under single ownership and developing the leases in an orderly manner. It will be of interest, however, to consider some of the influences which are imposed on ultimate recovery from employing unit operation.

Sand, gas and paraffin problems, as related to pumping operations, exist in an advanced stage and have been effectively relieved only by extensive experiments and test work. The excellent outage record of the Haverhill wells, and its comparison with the production outage at similar, but segregated properties, represents an increased producing efficiency exceeding 4.5 per cent. This benefit has been made possible largely by graveling "sandy" wells, by standardization and the installation of efficient equipment, by the careful and proper completion of wells, and by the generally efficient operation and supervision that is made possible by centralized activities.

With no outside interest in the pool, it is potentially an excellent property for repressuring. Based on results secured in other districts, the Empire company is anticipating, from future repressuring operations, a 20 to 25 per cent. addition to the normal ultimate yield. Single management and pooled ownership of a group of leases that are suitable for repressuring eliminate the common controversy, from the operators standpoint, of injection well spacing. With varied ownership, it is doubtful that the net cooperation in a Haverhill repressuring project would exceed 80 per cent. and might be a complete failure.

The Empire company had no desire for a high early peak. With no offset drainage, no formation gas to materially assist in the flush production, together with a weak market, it is felt that no damage has been inflicted on ultimate returns. In sacrificing the high flush to be obtained from rapid development, the property normally would be operated about 510 days longer in reaching its economic limit. This apparent loss is to some extent offset by the 4.5 per cent. reduction in down time which stands to decrease the profitable period by 555 days. Another important influence, which will increase ultimate returns by employing unitization, is the elimination of all beam wells which, in the case of Haverhill, means increasing the economic earning limit of all such wells by $52 per average well month.

Summary

In being able to develop and operate the group of Haverhill leases as a unit, the Empire company estimates that the following savings have been made:

Development	
Net savings in equivalent dry holes	$252,000
Net savings in drilling expense	63,000
Net savings in pipe line system and lease tankage	23,500
Benefits from purchase discounts and standardization	28,000
Net savings in buildings and dwellings	8,000
Net savings in well and pumping equipment	86,800
Net savings in water and gas systems	15,000
Net savings in tool work	9,000
Savings in interest on reduced cash requirements	26,000
Savings in interest on reduced capital investment	81,000
Total development benefits	$592,300
Operation	
Estimated savings in operation and maintenance expenses	$284,000
Production	
Not considered	
Total Benefits	
Total benefits from development and operating economies	$876,300
Total benefits the first three years	769,300
Total benefits remaining life	107,000

This total benefit in the amount of $876,300 is equivalent to 46 per cent. of the total actual development expense, and of this 46 per cent., all but 6 per cent. would be realized during the first 3 years. Over the producing life of the property, the total net accountable benefit from having the group of leases assembled and under single ownership and management is represented by savings in total expense that are equivalent to an average annual earning of 3.5 per cent. on the gross capital investment.

An indirect benefit that has not been mentioned as favoring the principle of unit operation is the protection of the crude market and the individual producer and royalty owner against the penalties of overproduction caused by unnecessary flush oil and untimely development. As example, the combined Haverhill leases were developed during a trying period with a flush peak of 2400 bbl. as compared with 7500 bbl. or more, if drilling had been normally competitive.

Conclusion

The cited benefits that will accrue from developing and operating the Haverhill pool as a unit will not individually occur as economies in another unitized pool. Peculiar problems and conditions that exist in one area may not be encountered in a corresponding degree of importance in another, but, in general, such differences should be compensative for different pools that are comparable as to size and general characteristics.

The economies derived from the unitization of the Haverhill pool are an example of what might be expected from a general application of the plan. Under the existing and anticipated earning status of the business, from royalty owner to refiner, such potential savings cannot be disregarded. They should be an incentive and stimulus for ironing out apparent obstacles to unitization with the ultimate aim of the industry to apply its principles to the maximum.

Suggested Procedure for Exploitation of an Oil-bearing Structure by Unit Operation

By C. S. Corbett,* New York, N. Y.

(Tulsa Meeting, October, 1929)

There is much comment at present in the ranks of the oil industry regarding unit operation of oil fields and the benefit that would accrue if it could be extensively applied. It seems certain that, as an immediate corrective of the present situation, overproduction could be effectively curtailed with all the advantages of proper conservation of petroleum resources and with no important loss to anyone connected with the industry.

Unit Operation in Certain Foreign Fields

Many an oil operator in America would doubtless like to have exclusive control of one or more oil-bearing structures for development in accordance with the economic position of the industry and especially in accordance with the best production practice known. A few operators now have this privilege, particularly in certain foreign fields, and are following lines of procedure which show that they are aware of the great opportunity that is theirs. We find in an article by Professor Strigeoff,[1] and in a paper read by Captain Comins[2] before the American Petroleum Institute, the outlines of procedure adopted, respectively, by the Soviet Government for the nationalized Russian oil fields and by the Anglo-Persian Oil Co. for its fields in Persia.

Comprehensive plans for the unit operation of other oil fields may have been described publicly but no such descriptions have come to the attention of the writer. New fields are coming more and more into the hands of single operators or of a few who control large activities and who appreciate fully the need for cooperative action and are willing to forego the lure of a large quick profit from high flush production in order to secure the advantage of better stabilization in the industry and a larger though more deferred profit by operating the field as a unit. Much can be done toward efficient development of an oil field controlled by a few operators who are willing to cooperate for that purpose, but the best result can be obtained only by pooling their interests in the field

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[1] J. M. Strigeoff: Russian System of Field Development. *Oil & Gas Jnl.* (Apr. 5, 1928) **26**, No. 46, 67.

[2] D. Comins: Unit Operations in Persia. Amer. Petr. Inst. *Bull.* (1929) **10**, No. 2, 32.

and operating it as a unit. It is an encouraging sign in the industry that the pooling of interests in various fields is being more and more discussed.

The Persian fields are of the less common type in which the reservoir storage space consists of relatively large communicating openings in the nature of crevices and solution cavities. As pointed out by Captain Comins, the systematic collection of data and their correlation have indicated clearly the measures to be taken for the proper development of the field. In the more common type of oil field, in which the reservoir storage space consists of the small interstices between sand grains, the measures to be taken for proper development cannot be so clearly indicated during the life of any particular field because of the lack of easy movement of gas, oil and water through the reservoir rocks. It will probably be a long time before the best plan of operation for fields of this type will be definitely established from actual field results. In the meantime, the subject must of necessity be considered largely from a theoretical standpoint.

Shortly before the appearance of the paper by Professor Strigeoff, the writer had formulated a plan for the unit operation of the common type of oil field (having a sand or porous sandstone as reservoir rock) which was practically the opposite of that advocated by Professor Strigeoff. It is the purpose of this paper to outline this plan and to present the considerations which lead to the belief that it will result in the largest ultimate yield and the largest profit to the operator.

Outline of the Procedure Recommended

For convenience and because it is considered the ideal structure for oil accumulation, the elongate dome type of structure is used in this discussion, but the procedure described can be adapted just as well to oil accumulations that owe their concentration to other structural conditions, except those rare instances where the oil is in synclines because of lack of water in the rocks. As indicated above, the plan is proposed only for fields in which the reservoir rock is of the nature of sand or sandstone as to its storage characteristics—that is, a rock with small openings serving as the collecting space, rather than one with large openings, such as the honeycombed or cavernous limestone found in the Persian fields and in the South Fields of Mexico. In brief outline, the procedure advocated by the writer is as follows:

1. Exploitation to begin with the taking of oil from wells which penetrate the producing formation a short distance (the first locations) down the dip beyond the limits of the free gas in the crestal part.

2. Wells at locations successively down the dip to be drilled and brought into production as needed to maintain the required supply, the wells which have been producing being closed when their gas-oil

ratios become excessive as a result of the free gas in the formation gaining access to them.

3. Gas produced with the oil (principally, of course, out of solution in the oil) in excess of the amount actually needed for use in the field to be returned to the formation through one or more wells penetrating the oil-bearing horizon in the free-gas area.

4. When the field has been completely worked over and production has begun to fail in the lowest flank locations, edge-water encroachment to be used, aided if necessary by artificial water-flooding methods, and the field to be worked over again by opening wells successively in reverse order up the dip as needed. It will probably be inexpedient to return gas to the producing horizon during this stage unless the field pressure has dropped to a very low level.

The first stage (working down the dip) makes use of gas drive, the second stage (working up the dip) uses water drive, and the combination of the two should give a larger ultimate recovery than could be obtained by any other means short of mining for the oil. Gas stored in the formation during the first stage would be removed with the oil during the second stage and its eventual recovery would be practically complete. Properly carried out, a minimum of oil will be by-passed by the gas drive and this will be mainly in the form of films adhering to the sand grains by absorption and held by capillarity. It is such retained oil that the water drive is particularly efficient in "prying loose," especially if a solution of sodium carbonate is used.

This brief statement of the plan is presented so that the reader may have the outline clearly in mind. The remainder of the paper gives in some detail considerations relating to oil accumulation in general and the recommended plan of exploitation in particular, so as to point out adequately its advantages.

Conditions in Oil Fields

In most domes containing a commercial oil accumulation, the reservoir formation carries, in addition to the oil, hydrocarbon gas in the free state and in solution in the oil, and also salt water. The arrangement of these substances in the reservoir formation is the one familiar now to practically everyone at all interested in geology or in the producing phase of the oil industry; namely, the free gas at the crest of the dome, oil below (that is, down the dip from) the free gas accumulation and therefore structurally lower than the gas and surrounding it in areal distribution, and finally the salt water, in turn lower than the oil and surrounding it in areal distribution. Though these broad relationships are generally understood, it is doubtful whether a true picture of the horizontal and vertical scale, which commonly applies to the distribution of the three substances, is so widely held. Fig. 1, which shows a diagrammatic

cross-section of a typical oil-bearing dome, may help in respect to thinking to scale.

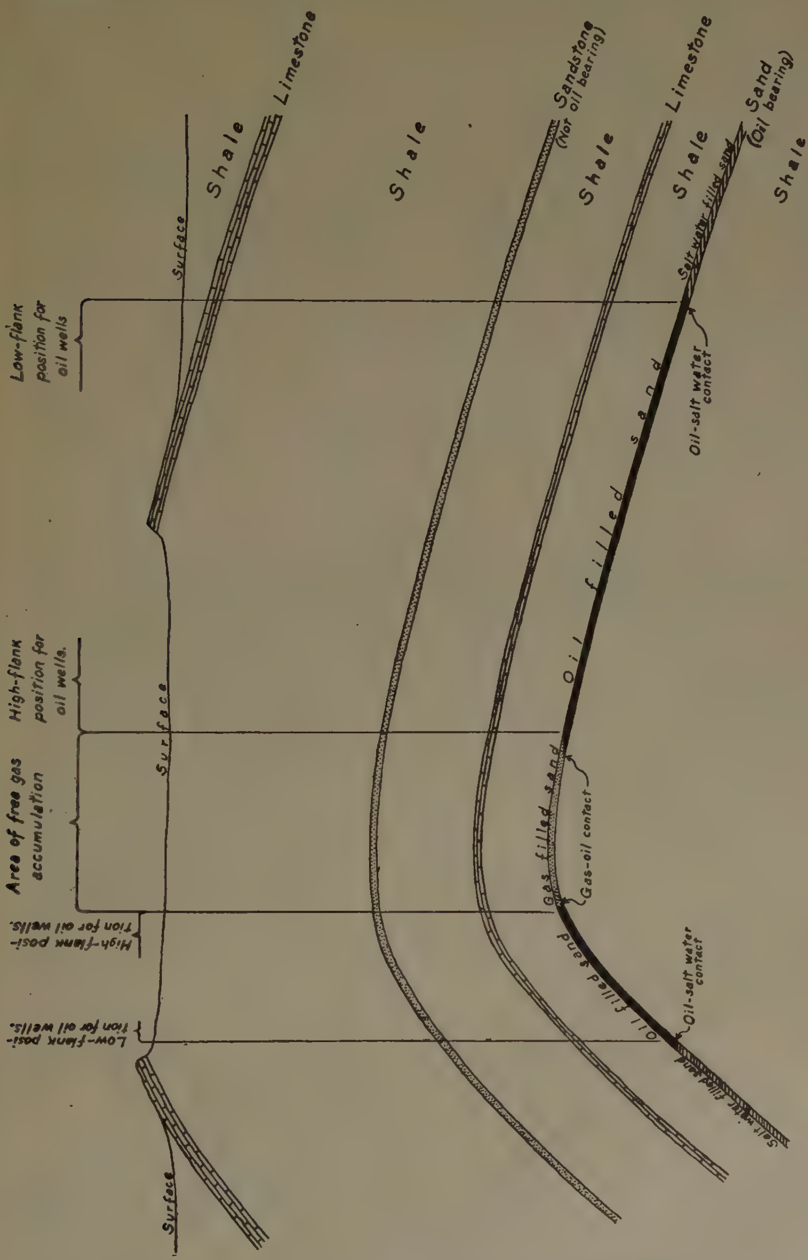

FIG. 1.—CROSS-SECTION OF TYPICAL DOME SHOWING DISTRIBUTION OF GAS, OIL AND SALT WATER IN AN OIL-BEARING STRATUM.

Horizontal and vertical scales the same.

The point to be emphasized here is that the thickness of the reservoir bed is ordinarily slight relative to the horizontal distance through which

it stretches across the structure. In exceptional instances, which happen to be common in California, we hear of producing zones hundreds of feet thick. Even there, however, it is probable that the thick zones are made up of scores of reservoir beds which, separated by relatively impermeable layers, function independently in yielding the oil or gas stored in them. In general, the ratio of the thickness of the producing bed to the distance through which the accumulated oil and gas extend across the structure is roughly of the order of 1 to 100. With the surface of separation between the free gas and the oil and that between the oil and the salt water approximately horizontal, and with the beds everywhere inclined except at the crest, this limited thickness of a producing sand means that, throughout most of the area of oil and gas accumulation, a well drilled through the producing sand will encounter only free gas or only oil (with dissolved gas). In a narrow belt near the lower edge of the oil accumulation, such a well would encounter oil and water in the sand, and in a narrow belt near the upper edge it would encounter free gas and oil. Fig. 1 illustrates these statements.

Expedient Objectives in Oil-field Operation

There is general agreement among petroleum engineers that wells which penetrate the gas-bearing portion of a reservoir formation should be kept closed. There are two strong reasons for doing this: (1) to conserve the underground pressure because of its value in oil production, and (2) to prevent oil from having access, as a result of gas drainage, to the dry sand of the free-gas area, since it is probable that most of the oil moving into the dry sand would not be recovered, except possibly by water-flooding methods in the final period of operation of the field. The temptation to take gas from such wells merely for use on the lease should be resisted and every feasible effort made to avoid such use. In no case should an attempt be made to turn a gas well into an oil producer by letting it blow off into the air. Production should be taken entirely from wells situated far enough below the crest so that free gas does not have access to them, except temporarily as noted below. Most of these wells will be situated on the flanks, a few will be on the plunging axis of the dome. It is only in the order in which these wells are brought into play, and in the choice of wells used for the return of gas to the sand, that further procedure in operating the field can be varied.

In the development of every field that can be handled as a unit, it should be the aim of the operator, within the limits of maintaining the proper balance between costs and profit, to secure the maximum amount of oil with the minimum amount of underground movement of the oil to reach the wells. Such movement requires energy, and unnecessary travel consumes energy which, if saved, can be used for extracting more oil, thus securing a larger ultimate yield from the field. To accomplish

this aim is not entirely a matter of well spacing, though that feature is exceedingly important. Whatever system and interval of well spacing is chosen, it is very important that each unit of oil recovered be taken, as far as possible, from the well which penetrates the sand nearest to it.

Methods of Attaining Desired Objectives

One possible way of securing the desired result of producing oil from a field with a minimum amount of underground movement of the oil to the wells may be by completing all of the wells before extraction of oil is begun. The oil would then be drawn from them all simultaneously and such adjustments in rate of flow would be made from time to time as necessary to effect a uniform drop in pressure throughout the field.

An important objection to this method is that there would be no opportunity for return of gas to the sand, since the localization of the returned gas would upset the uniform pressures to be maintained if the oil is to be prevented from traveling more than the shortest distance necessary to reach an outlet. No considerable pressure would remain in the formation to assist in recovering the oil left as films adhering to the sand grains and held by capillarity.

In any case, the economic necessity of securing early returns on a large investment requires that oil be taken from a field concurrently with its development; that is, long before it is completely drilled.

There seems to be a rather widespread idea in the ranks of the oil industry that, in unit operation, the early production should be taken from the low-flank wells,[3] moving up the dip as development proceeds. Some engineers, for example Professor Strigeoff, would depend upon edge water to follow up the dip as the oil is exhausted and thus aid in bringing oil to the wells. If edge water does not follow readily and with sufficient pressure, artificial flooding is to be used. No provision is made for return of excess gas (out of solution from the oil produced) to the sand, since it will not be needed. The gas in the crest of the structure serves no other purpose than to hold the body of oil in its original position—an important service, however, in that it would prevent the oil from moving upward into dry sand where much of it would not be readily recoverable.

Others would select the low-flank wells for the earliest production for one or both of two other reasons; namely, (1) the belief that repres-

[3] For convenience in reference, the term "high-flank wells" will be used for wells that penetrate the oil-bearing sand in the higher part of the area of oil accumulation (as it exists at the beginning of development), but not touching the free gas accumulation, and "low-flank wells" for those that penetrate the oil-bearing sand a short distance above the limits of salt-water accumulation. Wells on or near the plunging axis have essentially the same significance with respect to development of the field as flank wells.

suring by introducing gas into low-flank wells is the most effective method, and (2) the supposition that oil produced from low-flank wells will be obtained with a lower gas-oil ratio than from high-flank wells. These ideas will be discussed at appropriate places later.

The writer believes that there is much more to be gained by the recommended procedure, as outlined above, in which the free gas is used as the driving agent in first working over the area of oil accumulation and water is used as the driving agent in a second and final reworking of the area.

Advantages of Proposed Plan

1. *Maintenance of High Pressure in Reservoir*

The maintenance of high pressure in the reservoir formation and the successive extension of the free gas accumulation of the crest of the structure into the drainage areas of the wells is an important advantage. In the vicinity of wells being produced, the formation pressure will be lowered, of course. Widening of the drainage area of each producing well will be gradual. On account of Jamin action,[4] pressure decrease will not at any time extend far beyond the drainage area of such a well. The drainage area will enlarge as the oil is extracted until, through the combination of its extension and of the lowered pressure therein, the high-pressure free gas a short distance up the dip breaks through and the drainage area becomes part of the free-gas area. Thus practically all of the flush-production oil in the drainage area of each well is obtained with the minimum of underground movement to the well and therefore with the least possible expenditure of energy.

A rise in gas-oil ratio of any well should occur when the high-pressure free gas has broken through. According to Captain Comins' discussion of the Persian fields, this rise is very gradual; but obviously it may be expected to be more rapid than it would be if the free-gas area had no connection with the well. The well may be continued in production as long as its daily yield of oil warrants. Since the excess gas is returned to the sand, the production during this period is by an operation which is in effect a gas-lift. Captain Comins found such conditions in the Persian fields, for he says: "In the early stages of going to gas, the increased supply at the feet of the wells acted as a natural gas-lift, and the production of such wells was materially increased."

As soon as the well is closed, high pressure will be reestablished throughout its drainage area, as a result of which the gas disseminated

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[4] S. C. Herold: Jamin Action—What It Is and How It Affects Production of Oil and Gas. *Bull.*, Amer. Assn. Petr. Geol. (1928) **12**, 659. Also, Analytical Principles of the Production of Oil, Gas, and Water from Wells. Stanford Univ. Press (1928) 410.

through the residual oil in the form of small bubbles should be in large measure redissolved. So far as this takes place, the oil will then become free-draining and can flow off down the dip to join again the main body of oil.

2. *Maintenance of Relative Position of Gas and Liquids*

The maintenance, during the entire producing life of the structure, of the same relative position of gas and liquids as that in which they were originally arranged during accumulation, with provision at the same time for return of gas to the sand without disturbing this arrangement, is the second advantage. The use of edge water as the agent to follow up the oil from the beginning does not, of course, disturb the natural arrangement, but also it does not provide for the return of gas to the formation.

As mentioned, some petroleum geologists and engineers recommend that excess gas be returned to the sand through low-flank wells. They favor this because gas, introduced into an oil-bearing stratum, has been found to move up-dip more readily than down-dip. They would take advantage of this tendency by having the gas push oil upward into wells situated structurally higher. This procedure would place gas in the reservoir formation between the oil and the salt water; that is, out of its proper place on a gravity basis. Moreover, it takes no account of the reason for the gas moving up-dip more readily than down, which is simply that the gas is lighter than other fluid substances in the formation. Consequently, if gas introduced into flank wells pushes oil upward into higher wells, it is only because oil or heavier gas is working downward elsewhere and forcing the introduced gas upward. As far as relief of pressure alone is concerned, gas will move in one direction as readily as in another. Therefore, when gas is introduced in the crestal part of the structure and cannot move further upward, it must exert a downward pressure on the oil below and drive it toward wells lower on the structure.

The acknowledged tendency for gas to work up the dip is a strong argument for introducing it in the crestal part of the structure and getting the direct benefit of its downward thrust against the oil. The strength of this tendency is a measure of the ability of gas to separate from oil on a gravity basis and indicates that, if kept in its normal position above the oil, it can be used effectively as an advancing wall to drive oil down-dip ahead of it. Using it to drive oil upward in the manner some have recommended would be, in unit development of an oil-bearing structure, an indirect method of taking advantage of the feature discussed.

3. *Mobility of Gas*

The third advantage lies in the greater mobility of gas than of water and its unlimited expansibility, whereby it can readily keep pace with

the extraction of the oil and will maintain a pressure thereon subject neither to interruption nor to sudden reduction. The greater mobility of a gas than of a liquid is too well known to require discussion. Its property of expanding to fill all the space available to it gives assurance that the pressure it will exert on the oil will be uninterrupted regardless of speed of withdrawal of the oil.

4. *Regularity of Surface between Oil and Gas*

Greater regularity of surface between the main body of oil and the free gas acting upon it as the driving agent, providing channeling is avoided, forms another advantage. This effect is perhaps more speculative than any of the other advantages discussed, but it seems to the writer none the less probable and fully as important as some of the others. While not much quantitative information is yet available as to the effect of dissolved gas upon the viscosity and the surface tension of oil, it has been definitely shown by Beecher and Parkhurst[5] that both are appreciably reduced by dissolved gas. By virtue of lower viscosity the upper surface of the body of oil will tend to remain smoother and more nearly horizontal during its downward movement. Because of a lower surface tension and resulting decrease in capillarity, a larger percentage of oil will drain from the sand as the surface of the oil body recedes. These two features, together with the minimizing of the effect of disseminated gas bubbles discussed under advantage 1, would tend strongly toward the maintenance of an even receding surface of the body of oil, thereby reducing the opportunity for the advancing front of the free gas to by-pass important quantities of recoverable oil.

In contrast to the effect just described, if oil is taken from low-flank wells and edge water is used as the driving agent, the lowered pressure and accompanying decrease in dissolved gas will mean higher viscosity, higher surface tension with resulting increase in capillarity, and pronounced Jamin action. Irregularities which develop in the receding surface of the body of oil are thus more likely to remain and eventually lead to the by-passing of important amounts of oil that otherwise would be recovered.

A contributing factor of probable importance in producing a more even surface in the use of downward gas drive than in the use of upward water drive is that of specific gravity differences. In a recent discussion of gas traps,[6] the statement is made that "in raising the pressure from atmospheric to 300 lb. the proportional densities of the oil and gas change from about 880:1 to 41:1." Assuming that the change continues

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[5] C. E. Beecher and I. P. Parkhurst: Effect of Dissolved Gas upon the Viscosity and Surface Tension of Crude Oil. Petroleum Development and Technology in 1926, A. I. M. E. (1927) 51.

[6] C. C. Taylor: Modern Gas Trap Installation. *Oil Weekly* (1929) **25**, No. 13, 32.

at essentially the same rate, the ratio of densities of oil and gas at 1000 lb. per sq. in.[7] would be about 11:1. This is in contrast to a ratio of densities of oil and salt water of approximately 0.7:1 or 0.8:1. These ratios may not be strictly accurate or invariable but they give a fair idea of the order of magnitude of the difference. It is entirely reasonable to suppose that two fluid substances in contact will tend much more strongly to maintain a horizontal surface of contact when the ratio of their densities is 11:1 than when that ratio is only 0.8:1.

5. *Time for Oil to Drain into Wells*

The fifth advantage is the extended period of time during which any oil that may have been by-passed by the advancing front of the free gas accumulation can be draining toward producing wells. Under advantage 1 has been mentioned the assistance which the reestablishment of high pressure would give, on account of re-solution of disseminated gas bubbles. In proportion as the gas bubbles are removed, the oil becomes free draining, except the portion of it held by adsorption on the sand grains and by capillarity between grains. The drainage will be downward, caused by gravity and by the downward circulation of gas through the sand, especially if some production is taken from wells to which free gas has access. At best the drainage will be slow, consequently the value of a system of production that affords a long time for drainage of oil left in the sand will be enhanced by reason of this long period of drainage. In contrast to this, we may be reasonably sure that oil by-passed in the use of water drive is thereby wholly lost.

6. *Recovery of Flush-production Oil with Appropriate Gas-oil Ratio*

The sixth advantage is the recovery of practically all of the flush production oil of the field with a gas-oil ratio always appropriate for the oil being produced at any time during the development of the field. This naturally follows from the consideration, developed under advantage 1, that practically all of such oil is obtained with the minimum of movement to the well. That is, if the oil in various parts of the structure has varying amounts of gas in solution, the gas-oil ratio involved in its recovery will vary more or less directly in relation to the amount of gas in solution, other things being equal.

Very little information seems to have been made public regarding the relation between gas-oil ratio and structural position of producing wells in various fields. Two fields are cited in a recent report,[8] in which wells high on the structure produced with higher gas-oil ratios than wells

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[7] Bottom-hole pressures of 1000 lb. per sq. in. are commonly found at depths of about 2500 feet.

[8] Function of Natural Gas in the Production of Oil. A Report of the U. S. Bureau of Mines and the American Petroleum Institute, 1929, pp. 45 and 55, respectively.

situated lower. One is the Rainbow Bend field, Kansas, where "the gas-oil ratio increased progressively from 2000 cu. ft. per bbl. on the flanks to 7000 cu. ft. per bbl. on the crest of the structure. There was also a variation in the specific gravity of the gas from 0.89 (air = 1) on the flanks to 0.73 on the crest." The other is the Salt Creek field, Wyoming, where "data gathered from approximately 100 Second Wall Creek sand wells . . . show that wells located low on the structure had lower gas-oil ratios than those located at structurally higher elevations." The increase in gas-oil ratio amounted to 500 cu. ft. per bbl. for each structural rise of 200 ft. The following statements are given in explanation of this increase at Salt Creek: "Undoubtedly this fact is due to the tendency of the gas to segregate from the oil and migrate towards the top of the structure. That such segregation occurred was definitely proved when the field had declined to the pumping stage and wells on top of the structure began to produce increased quantities of gas. There was no evidence of any segregation of gas from the oil and its migration to structurally higher points during the early life of the field." It is possible that the same explanation may apply to the Rainbow Bend field. In general, it seems likely that such a situation would arise in any strongly competitive field. The rapid drilling of wells in all parts of the field would give early opportunity for gas to segregate from the oil in the drainage areas of the lower wells and move upward into the drainage areas of higher wells, thereby raising the gas-oil ratios of production in the latter.

The reverse was found to hold in the Persian fields, where according to Captain Comins, "wells down the flank have greater rock pressures and, therefore, greater gas-oil ratios than wells up the flank (excluding those very near gas-oil level)."[9] Captain Comins also said that in the Naft Khaneh field, a mathematical relation between gas content and oil pressure up to 1500 lb. per sq. in. had been determined experimentally, and that this relation was found to apply very closely to conditions in two other fields situated "hundreds of miles from Naft Khaneh." The gas increased with pressure, not in direct ratio but at a rate somewhat greater than in proportion to the square root of the pressure, as may be seen by the mathematical expression given: $G = 1.36\ P^{0.558}$ "where P is the oil pressure (gage) and G is the gas content at that pressure." The Persian data are from fields in which the oil-bearing formation is honeycombed or cavernous and the production is under hydraulic rather than capillary control. The gas produced with the oil in each well, therefore, represents all the gas from solution in the oil being currently produced, and little or none segregates in the formation.

It is highly improbable that the nature of the reservoir formation will affect materially the original relation between gas content and pressure,

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[9] D. Comins: *Op. cit.* The parentheses are part of the quotation.

though in the two preceding paragraphs the statements indicate that it may influence the gas-oil ratio of production under certain conditions.

The high gas-oil ratios of high-flank wells in fields developed competitively may be simply another indication of the inefficiency of the use of gas pressures in such development. They give no assurance that, in the systematic development of such a field, there is anything to be gained by starting with low-flank wells and working up the dip as against starting with high-flank wells and working down the dip. The best that one can hope for in the productive life of a field as a whole is that the oil be produced with a gas-oil ratio proportionate to the amount of gas dissolved in the oil, under conditions in which the pressure of this gas is used as effectively as possible under current economic conditions in the industry.

7. *Relatively Small Investment in Drilled Wells*

The relatively small investment in drilled wells required in advance of their actual need to maintain production is the seventh advantage. In order to put the proposed plan into operation, it is only necessary to complete enough wells to permit taking the required daily production of oil from just below the limits of the free gas accumulation, having one well in the free-gas area for return of gas. While it may be desirable rather early in the life of the field to determine the lower limit of the oil accumulation for the purpose of estimating reserves, no immediate search for that limit is necessary, as would be the case for any plan contemplating the use of low-flank wells in starting the exploitation of the field. In fact, the operation of the plan advocated here would call for a minimum advance investment in drilled wells and for few, if any, expensive installations or investments other than would have to be made in any circumstances for the field. The required daily production can be taken from many wells at a low daily rate per well or from as few wells as needed to supply the amount at capacity production, depending upon which policy—production under back-pressure or open-flow conditions—gives higher efficiency for the field under exploitation.

8. *Amount of Oil Obtained as Flowed Production*

The larger amount of oil from the field to be obtained as flowed production is the eighth advantage. It is believed that the maintenance of the high pressure in the reservoir formation by the procedure outlined will result in recovery of a very large proportion of the total oil obtained by free flow from the wells. Indeed, all of the oil obtained from each well up to the time it is closed in, on account of encroachment of the expanding area of free gas, should represent flowed production. Therefore there should be less need for the direct application of the gas-lift,

with its attendant problems and the requirement of closer supervision by production engineers.

Conclusion and Acknowledgment

The writer recognizes the fact that some of the advantages claimed are based upon theoretical considerations which have not yet to his knowledge been demonstrated by results attained in actual trial. However, little progress would be made in any field of human endeavor if plans or ideas that appear favorable "on paper" were not actually tried, provided they can not be thoroughly and unquestionably discredited by counter considerations. It is hoped, therefore, that this paper will bring further attention to the problem of unit operation of oil fields, will lead to discussion and, eventually, to early thoroughgoing trials where conditions of ownership permit.

The writer gratefully acknowledges his indebtedness to J. Volney Lewis, chief geologist for the foreign operations of the Gulf Oil Corpn., and to Prof. A. N. Winchell, of the University of Wisconsin, for critically reviewing the manuscript of this paper.

DISCUSSION

R. W. Brown,* Tulsa, Okla.—If a pool were developed in accordance with the proposed plan a long period of time might be required for its development and the rate of production would be decreased. As noted by Mr. Corbett, the deferred development results in less initial investment and smaller interest charges. This is particularly true where the drilling costs are great, but where the leasehold costs are large as compared with drilling costs this factor is of relatively little importance. Indeed, if large sums have been paid for the oil rights, the annual earnings might be reduced to the point where a large part of them would be required to pay the interest on the original investment. In any case the present value of the future earnings would be reduced, and in certain cases possibly more so than would be compensated by the increased production (if any). For example, using an interest rate of 10 per cent., 1,500,000 bbl. of oil recovered mostly in one or two years will be worth 50 per cent. more than 2,000,000 bbl. of oil recovered equally over a period of 20 years, assuming the same net income per barrel. Assuming an interest rate of 10 per cent., $1 received 10 years hence is worth only 38 c., and $1 received 20 years hence is worth only 14 c. at the present time. The interest factor thus places a definite limitation upon any plan that increases the time during which oil can be recovered, as income received after a period of 20 years has relatively little value. In order to test the value of the proposed plan (where increased production can be anticipated by its adoption) it is suggested that certain estimates, or assumptions (in case there are insufficient data for estimates) be made regarding the rate of production, income, and costs under two or more plans and then valuations made using the present value method to determine which plan is the more profitable. The writer does not wish to predict the results of such an analysis in a given case, as other factors besides interest and discount must

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be considered, but in certain cases interest and discount may well outweigh any beneficial results to be gained from the adoption of the proposed plan.

C. S. Corbett.—Mr. Brown's comments are well taken as a reminder that economic considerations must not be overlooked in the exploitation of an oil field.

In emphasizing two advantages of the proposed plan, the impression may have been given that the recovery of oil from a field so operated would necessarily be slower than by other methods of unit development. Actually, there would seem to be no valid reason why production could not be at as high a rate as in any other method, except perhaps one in which as many strings of tools were used as in the development of a highly competitive field. Avoidance of such feverish activity is one of the mainsprings of the unit operation idea. At the present time, in fact, practically the entire oil industry in America is convinced that a larger return on investment is to be obtained by deferring development somewhat than by continuing at the former headlong speed that had seriously affected the price structure of petroleum products.

It is quite possible that much of the increase in ultimate production which it is believed the proposed method of exploitation will afford could not be recovered until after the time when the production of the field would otherwise be of little or no consequence. This is not a case of postponing the recovery of oil that might be produced earlier but rather one of securing oil that would otherwise presumably be left in the ground. The present worth of such oil may be nil but obviously it will attain value later in the life of the field. Though the lateness of recovery of this additional oil is unavoidable, the profit on it when finally produced should be so much clear gain to the operator.

Production Engineering

Production Engineering in 1929*

By C. V. Millikan,† Tulsa, Okla.

(New York Meeting, February, 1930)

Production engineering has continued its rapid progress during the past year. Many engineering efficiencies long practiced in other industries are being rapidly accepted by the oil industry, and every branch of development and production work is undergoing study that is reducing the time and hazard in the drilling of wells even for greater depths, is securing better service from equipment, and is obtaining greater ultimate recovery from the reservoirs.

Deviation of Drill Holes

Deviation of drill holes probably has attracted greater and wider study than any other subject. Until about one year ago it had been given little attention. Some California operators knew the common magnitude of deviation, but Mid-Continent operators hesitated to believe that holes could be drilled so crooked. The great emphasis and publicity given to the seriousness of the problem resulted in the design of many instruments to record the deviation by chart or photograph. Instruments which would give the direction as well as deviation were not generally favored because of the grave fears of the legal complications which might result if the bottom of a producing well should prove to be on a neighboring lease. With all the instruments available for determining deviation, the use of etching on a glass bottle by hydrofluoric acid is still the most common method employed.

The beneficial result of this earnest effort to drill straighter holes is proved by a comparison of deviation of wells completed recently with those completed over a year ago. The time of this change is arbitrarily taken as Jan. 1, 1929, as at that time the operators were aware of the deviation which usually occurred, and most of them were making some effort to reduce it. Table 1 shows averages of wells completed by several companies. Data on a few wells outside the greater Seminole area are

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† Production Engineer, Amerada Petroleum Corpn.

included. The depth and drilling time are for only the portion of the hole drilled by rotary, and the deviation is expressed in terms of the vertical correction.

TABLE 1.—*Averages of Wells*

Period in Which Wells Were Completed	Number of Wells	Depth, Feet	Drilling Time, Days	Footage per Day	Vertical Correction, Feet	Wells with 30 Ft. or Less Vertical Correction, Per Cent.
Prior to Jan. 1, 1929	103	3891	41	95	115	
Subsequent to Jan. 1, 1929	237	3862	40	97	26	
PROGRESS OF DRILLING STRAIGHTER HOLES						
Prior to Jan. 1, 1929	18	3795	54	70	12.6	25
Jan.–Feb., 1929	21	3980	47	85	16.0	55
March–April, 1929	17	3990	45	89	13.5	61
May–June, 1929	9	3775	37	101	10.3	43
July–August, 1929	36	3815	40	96	8.6	77
Sept.–Oct., 1929	29	3838	43	89	2.9	93

The first method of drilling straighter holes was by reducing the weight carried on the bit, which reduced the rate of drilling. The drillers soon learned that by using more even and better controlled weight on the bit, keeping the bits sharp, using bits with longer shanks, longer drill collars, reamers, and better control of slush pumps, as much footage could be made drilling straight holes as was made when less attention was given to these features. The lower half of Table 1 shows the progress of drilling straighter holes. It includes only wells that had a vertical correction of 30 ft. or less, the last column giving the number of such wells expressed in percentage of all wells on which data were available.

Reduced drilling costs, including labor, fuel, water, and casing, plus footage saved in straight holes over crooked holes, has probably amply repaid the industry for its effort to drill straighter holes. In addition to this, savings which are hard to evaluate but are of much greater importance are longer life for drilling equipment, fewer fishing jobs and redrilled holes, lower cost of operation and, most important of all, the increase in ultimate recovery resulting from more even spacing of wells in the producing formation.

DEEP WELLS

Wells completed below 6000 and 7000 ft. with high initial oil and gas production and closed-in pressure in excess of 2000 lb. have become so common as to create no more than passing comment. Such wells have required not only larger and stronger equipment both for drilling and for producing, but equipment of more efficient design. Correlative study

of drilling equipment is being made, particularly of rotary equipment in California, to obtain a better balance in the power and strength of the different parts, such as boilers, engines, draw-works and slush pumps. Such work will reduce hazards of drilling and obtain a greater development efficiency. Casing made of steel with a minimum tensile strength of 95,000 lb. is commonly used in the deeper wells, while heretofore but little casing has been required better than A. P. I. grade C (minimum tensile 75,000 pounds).

Pumping and Repressuring

Pumping equipment has been studied closely, with sucker rods receiving probably the most detailed work. Dynamometers of several styles have been developed and improved, and nearly all the larger companies are using them to determine the best pumping condition and improve the efficiency of transmission of power from the prime mover to the sucker rods. Several of the larger companies have established laboratories to test material and equipment before it is recommended for field use, and better service records are being kept to determine what kind of equipment or material gives the most economical service. This type of work will have much more of the engineer's attention in the future.

Air-gas lift has not occupied the amount of engineering time in the past year that was given to it during the preceding two years. It has, however, been made more efficient in technology. Intermittent injection has probably received the greatest study and shows the greatest advancement, especially where two strings of tubing are used in such a way as to prevent back-pressure against the sand. It is interesting that this same method was successfully used in Pennsylvania as early as 1903. Intermittent injection where the same tubing arrangement is used for continuous injection is also becoming a more common practice. These improved practices, better understanding of lifting by continuous injection and more economic operation of gas-lift equipment, have reduced the economic limit of producing oil by air-gas lift.

Pressure maintenance work has been carried on during the past year with encouraging results. Wells in one field are flowing against a trap pressure of as high as 400 lb. and the gas is returned to the sand at a pressure of 1400 lb. Repressuring and gas drives are being used in younger fields than formerly, and also to retard water encroachment where rejuvenation of production may be secondary.

Underground Storage

Underground storage of crude oil was practiced by a California operator during the year. Excess production of several thousand barrels daily from one field was piped to another field partly depleted and owned in fee, where it was pumped into the producing formation with enough

gas to make a normal gas-oil ratio. While this work has not gone far enough to determine the final results, tests indicate that the older field has been rejuvenated sufficiently so that ultimate recovery may be expected not only of the oil that has been injected, but of an additional amount in excess of that estimated to have been recovered without rejuvenation. This is probably the most interesting, and may prove to be the most revolutionary, development in production practice during the year.

Trend toward Unit Operation

Production has been curtailed in some Mid-Continent districts because of limited market outlet, by applying a fixed ratio of reduction to all leases alike, regardless of other considerations. While such a procedure is not the soundest engineering practice, it does show that it is becoming easier to obtain agreement of operators to methods of producing which will be of mutual benefit, and will lead to the ideal condition—unit operation. The State of California has enacted a law to prevent waste of natural gas which, when intelligently enforced, will generally conserve gas energy and encourage cooperative agreements to the end of greater ultimate oil recovery.

The Petroleum Division of the A. I. M. E. at its October meeting conducted a comprehensive study of well spacing. With the coming of unit operation, problems of well spacing, sequence of development, conservation of gas energy and pressure maintenance will be of even greater importance than under competitive development, and therefore constitute the outstanding economic problems of the production engineer today.

DISCUSSION

D. C. Barton,* Houston, Texas.—Is the effect of the increased efficiency showing up in the costs of production in 1929 compared to those of previous years—is the increase in engineering efficiency showing up in the balance sheet in the cost of production?

C. V. Millikan.—It is showing up indirectly. It may not be an actual reduced cost but may be the same cost for deeper development, deeper pumping, and larger production of oil and water. Without these efficiencies costs would have increased greatly.

* Consulting Geologist and Geophysicist.

Chapter II. Well Spacing

A Theory of Well Spacing*

By W. P. Haseman,† Oklahoma City, Okla.

(Tulsa Meeting, October, 1929)

The well method of producing oil and gas is universally used in the development and operation of oil and gas properties. It consists essentially in the spacing of a number of wells on a given tract, and in drilling and operating them in accordance with established practices. The method is based on a fundamental energy principle. This principle governs the state and the change of state of fluids or fluid mixtures confined under pressure within a porous and permeable reservoir in such a way as to direct a flow from the reservoir into and out of a drilled well with a reduction of potential energy.

The application of the well method of producing oil has given data which prove that the total yield of oil from a reservoir through wells is, in general, only a small fractional part of the total oil that is contained in the reservoir. It is generally recognized that a spacing of one well to each 160-acre tract of any good oil pool is too wide. However, one well to this 160-acre tract will yield a large quantity of oil and in time will dissipate most, if not all, of the potential energy that was originally stored and retained in the fluids by pressure. Two wells spaced and drilled on this 160-acre tract would yield approximately twice the quantity of oil, while four wells would yield approximately four times the oil.

A well spacing is soon reached, with the addition of wells to this 160-acre tract, in which the drainage interference of offset wells will materially affect the yield of oil per well. The increased yield of oil, therefore, is not directly proportional to the added number of wells but the increased costs of development are directly proportional to the added number of wells. It is evident that while an added number of wells to this 160-acre tract yields an increased quantity of oil, there is an economic limit to the number of wells to be added. The yield of oil and the costs of development and operation are of such a nature, and are so related, that

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* For discussion by the author of his equation and its application, see his articles including charts and tables, in *Natl. Petr. News* (1929) **21,** No. 19, 59, and No. 23, 63.

† Consulting Engineer.

the net profit to be yielded from this 160-acre tract will increase to a maximum at some critical number of wells.[1]

A spacing of wells on a given tract which efficiently utilizes the natural potential energy in the fluids in the yield of oil is generally too wide for the efficient utilization of the artificial energy of repressuring. Added wells are essential, therefore, in most repressuring operations. These added wells, however, should be drilled in the early development of the tract and operated so as to secure added efficiency in the utilization of the natural potential energy in the fluids. The early addition of these wells up to a certain limit is more effective in securing an increased economical yield of oil than is the repressuring operation.

The spacing of wells is truly a scientific problem. It has been formulated and a solution has been reported in a recent paper.[2] The principles which control well spacing and which are essential to a formulation of the problem will be outlined and briefly discussed.

The yield of oil from a well is known to be affected by many and varied factors.[3] This fact precludes the development of a practical well-spacing formula which includes as many constants as there are factors. It is possible and of interest to classify and list these factors in groups and to analyze and formulate the well-spacing problem in terms of group factors. As a basis for this discussion the factors will be listed in two groups:

Group 1.—Fixed factors.

Group 2.—Variable factors.

Most of the fixed group factors define the conditions or characteristics of the reservoir stratum and the confined fluids which affect the yield of oil. The fixed group factors affect the potential oil of a pool that can be yielded by wells and determine whether or not an oil pool will be commercially profitable for any spacing of wells whatsoever. Among these factors are porosity, sand texture, cementation, specific gravity of oil, viscosity of oil, natural gas-oil ratio, thickness of pay stratum, saturation of pay stratum, etc. They affect the yield of the oil from a well in a more or less uniform manner for the various spacings of wells. The magnitudes and trends, if any, of their influences on the yield of oil are considered to be fixed and not materially altered, at least, by any spacing of wells such as would be used in the commercial operation of a given tract in an oil pool. The variable group factors are largely controllable factors and can be fixed at will. Among these factors are the spacing of wells, the timing of completion of offset wells, the depth of

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[1] W. P. Haseman: Profits and Proper Spacing of Wells. *Oil & Gas Jnl.* (Oct. 18, 1928) **27**, No. 22, 53.

[2] W. P. Haseman: A Formula Method for Well Spacing and Rate of Production. *Natl. Petr. News* (1929) **21**, No. 19, 59.

[3] *Idem.*

penetration of the pay stratum, the method of control of producing wells, etc.

It follows then, in case the operations are carried out on a given tract under such conditions that the spacing of wells is the only variable factor, that the yield of oil from a well or the tract can be expressed in a formula with one constant.[4] This constant is termed the spacing constant and its value is to be determined by field data.

Derivation of Formula

The production of oil by the well method is a phenomenon that is controlled by fundamental principles. These principles govern many natural phenomena such as monomolecular and radioactive changes. In picturing this phenonenon of producing oil, each producing unit, which consists of one well, the reservoir stratum and the confined fluids within the drainage distance of the well, is assumed to contain a definite and measurable quantity of oil. This quantity of oil is considered to be composed of two portions, the one portion termed *active* and the other *inactive*.

The active oil is energized by the gas and vapors associated and retained with it under pressure. It represents the potential quantity of oil that can be yielded by drilled wells. The number and spacing of the wells to a given tract determine, largely if not wholly, the efficiency of the yield of this potential oil. The inactive oil represents the quantity of oil that is held on the material grains of which the reservoir stratum is composed, and is otherwise held by films and allied molecular phenomena. The inactive oil must be treated or acted upon by some agent such as heat, chemicals, etc., before it is transformed into active oil and yielded commercially by wells. Now let

P_0 represent the total quantity of active oil under a given tract,

P_n represent the quantity of active oil that is yielded by n wells spaced to the given tract,

$P_0 - P_n$ represent the quantity of active oil remaining in the reservoir and which could have been yielded by added wells spaced to the given tract.

In accord with the principles that control these changes, an added well to the tract would have yielded an added quantity of oil proportional to the quantity of active oil remaining in the reservoir under the tract. Therefore

$$\frac{dP_n}{dn} = \lambda(P_0 - P_n)$$

Integrating and substituting limits,

$$P_n = P_0(1 - e^{-\lambda n})$$

[4] *Idem.*

This is a spacing formula which can be applied directly to the spacing of wells on tracts in an oil pool provided the operating conditions in the pool conform to the assumed conditions in the formula. When the operating conditions deviate from the assumed conditions, it is necessary to evaluate the disturbing conditions by special knowledge and formulas and to introduce an engineering safety factor into the result of the spacing formula.

This formula is most useful in the science of oil production. It gives new and needed data that check most favorably with available field data. In addition, it is the fundamental basis upon which there has been developed a practical method for the study and determination of the program of development and operation of an oil property that would give a greater yielding efficiency of oil and profit. The method is equally applicable to proved but undeveloped properties and to depleted but repressuring properties.

DISCUSSION

S. C. HEROLD,* Los Angeles, Calif. (written discussion).—If each of us was asked to develop a formula pertaining to the spacing of wells in accordance with known and most probable factors affecting production in any given field it is likely that no two such formulas would be identical. Probably most, if not all, of them would be adequate, but certainly some would be simpler than others, and therefore more convenient. Dr. Haseman gives one which I am inclined to accept as adequate and convenient because of its exponential form. If any difficulty is to be encountered in the use of his formula it will be on account of uncertainties respecting the values of quantities to be substituted.

I do not go as far as Dr. Haseman in supposing his equation to have a fundamental scientific basis in well or reservoir performance. It is rather, I believe, merely an approximation formula, an empirical formula, or a rule of thumb formula, the value of which depends solely upon its efficacy in giving a solution reasonably accurate as shown by later history in producing from the field. A formula of exponential form can be entirely adequate from a practical point of view while it is at the same time an absurdity purely from the theoretical point of view. In order that we may obtain an idea of the practical utility of his equation, Dr. Haseman has given us his Table 2.[5] No better agreement between actual and computed values should be desired.

The spacing constant, designated by the Greek letter lambda, so necessary in the use of this formula, is not fully explained. Seemingly it is the quantity wherein factors of Groups 1 and 2 enter. After reading Dr. Haseman's present paper, and its equivalent in the *National Petroleum News* of May 8, 1929, I feel that before pressing too strongly for information concerning it, one should carefully ascertain from Dr. Haseman an answer to the question, "Is the evaluation of lambda performed by a process or by a formula retained in secrecy?"

We are told that when operating conditions deviate from assumed conditions, it is necessary to evaluate the disturbing conditions, but if this is to be done by means of special knowledge, I am naturally curious about that special knowledge. Perhaps Dr. Haseman will favor us with a statement concerning its nature.

* Petroleum Geologist.

[5] *Idem.*, 63.

Dr. Haseman's formula, we learn, is equally applicable to proved but undeveloped properties. In this case, how may one evaluate the quantity P_0, representing the total quantity of active oil under a given tract?

The formula is said to be equally applicable to depleted but repressuring properties. I would ordinarily expect otherwise, in view of the fact that repressuring operations are usually equivalent to a forced drive. Where motion is confined to a circular area with natural flow, airlift and pump, it becomes elliptical in forced drive. This would throw the equation off considerably. Nevertheless, I would accept data in the nature of Table 2 as authority if and when such are available.

It is no difficult task to call attention to disadvantages displayed by any suggested formula. There is one outstanding advantage in the present one which we should not overlook; namely, that its use does not necessitate our understanding the intricate theoretical mechanics of reservoir performance. We need not concern ourselves with the capillary resistance due to alternating globules of oil and bubbles of gas in the interstices of the porous formation, nor worry in the least about the effects of back-pressures against production. These features are automatically cared for in a formula of this nature.

H. D. Wilde, Jr.,* Houston, Texas.—I prepared a written discussion, but Dr. Herold's comment agrees so well with mine, point by point, that presentation of mine does not seem necessary.

Member.—Is the evaluation of 50 per cent. the limit of recovery?

W. P. Haseman.—No, not necessarily so. Knowledge gained by extensive laboratory experiments and field operations at Pechelbronn give a maximum ultimate recovery around 50 per cent. An infinite number of wells drilled to a finite area is equivalent to a mining method of producing oil with very closely spaced tunnels.

The value of P_0 depends upon the sand and fluid conditions and may be as small as, say 10 per cent. and theoretically as large as 100 per cent. The shape of the curve and the values of P_n within the economic limits of n for a commercial pool is altered little by a change of P_0 from 50 to 30 per cent. or to 80 per cent in the formula.

For the special case where P_0 equals 50 per cent. and one well is drilled to each 10 acres with a yield of 15 per cent., substitute 15 for P_n, 50 for P_0 and 1 for n in the formula. The spacing constant λ is the only unknown term in the equation, $15 = 50(1 - e^{-\lambda})$. The numerical value of λ is the reciprocal of the number of wells to be drilled to each 10 acres to yield around 63 per cent. of the maximum possible yield of oil through drilled wells.

Member.—May I ask why you hit on 63 per cent.?

W. P. Haseman.—For the case where λ equals $1/n$ the equation becomes $P_n = P(1 - e^{-1}) = P_0(1 - 0.3678) = P_0(0.63)$. Therefore where $\lambda = 1/n$ the yield is $P_n = 0.63\, P_0$.

Member.—If you had three months production history on a well in that pool could you get the formula by production and not by curves?

W. P. Haseman.—I infer that you desire to know what spacing of the wells would be best in the pool. The formula is applicable to commercial pools only. In case the pool of which you speak is to be a commercial pool one can compute with considerable security the increased profits of one spacing over that of another spacing.

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* Director of Production Research, Development Department, Humble Oil & Refining Co.

The computation can in general be made on the first three months production of the discovery well.

Member.—How much could you improve on that if you had production data?

W. P. Haseman.—Additional production data, particularly production data of individual wells, are most valuable in more definitely defining the maximum net profit on the curve. Since in many commercial pools with a spacing of one well to each 10 acres the wells yield around 60 per cent. of their ultimate production within the first four months the flush production data are important.

Member.—You say that where operating conditions deviate from assumed conditions it is necessary to evaluate the disturbing conditions by means of special knowledge. Could you tell us about that special knowledge?

W. P. Haseman.—In the practical application of the formula such disturbing conditions as delayed completion of offset wells must be evaluated. This necessarily rests upon knowledge secured by some theory of decline of well production. The evaluation of such disturbing conditions can be made within economic security from present known data. Added data are much needed to more definitely define the limits of the constants in the formula. The details of this determination are too lengthy to be given here.

Member.—Dr. Herold's third question is: "Dr. Haseman's formula is, we learn, equally applicable to proved but undeveloped properties. In this case how may one evaluate the quantity P_0, representing the quantity of active oil under a given tract?

W. P. Haseman.—The quantity P_0 cannot be evaluated with numerical precision. In the practical application of the formula, since the expense of drilling one well is large, a considerable variation in the observed data may exist without seriously affecting the economics of the formula. The method of evaluating P_0 rests upon a theory of decline of well production.

In applying the formula to a practical case the acre and not the well is the basis upon which net profit is to be computed.

J. B. Umpleby,* Oklahoma City, Okla.—If you had the cost, and development cost is a big item, what effect would the yield of the wells have on the lifting cost? A 25 per cent. difference will make a big difference in the net profit. Are you figuring on the net profit?

W. P. Haseman.—I am figuring on the net profit per acre. The lifting cost has been considered in the net price per barrel of oil. The effect of this on the net profit per acre can be seen in the case of the curves of chart 3. The maximum net profit per acre shifts toward a wider spacing of wells with increased lifting costs, other factors remaining constant.

Member.—You should consider the percentage per barrel of net production if you are to have less cost per acre.

W. P. Haseman.—The net profit is figured on the basis of the acre and not on the well. The well cost is considered as an added investment in equipping the acre to yield oil. The oil is contained beneath the acre and not in the well. Whenever a given tract is proved with reasonable security to be commercially productive of oil there exists a considerable investment per acre in the tract and the maximum profit per acre of the tract can be secured by the added investment in the wells properly spaced.

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* Geologist and Petroleum Engineer.

J. R. Suman,* Houston, Texas.—This problem of well spacing is a most important problem to the petroleum engineer today and the problem we seem to know the least about. When we do learn something about it, we will be in position to develop a unit operated property.

In the development of a unit proposition, we have something to depend on in the place of well spacing. We should give attention to the maintenance of pressure until we learn something more about well spacing. Until then we cannot tell whether we are developing economically. We could well go to repressuring and forget well spacing. It seems to me to be ridiculous to drill the number of wells mentioned in the formula of Dr. Haseman for securing the maximum profit.

I would like to say a few words in behalf of the oil executives. Mr. McGraw of the Gypsy company has said that in the Seminole, if only one well had been drilled to each 20 acres, the profits would have been much higher. I do not know how Dr. Haseman arrived at the value of lambda, but Mr. McGraw arrived at this opinion by experience, and the spending of some $50,000,000 in this area, and I think the opinion of a man of experience is well worth consideration on one side at the same time you are considering a theortical proposition on the other side.

As I understand the formula, it applies principally to a structure where there is no water drive and no gas. I should imagine that 90 per cent. of the fields in the United States have the water drive and free gas, and therefore there must be a factor in well spacing to take these items into consideration. We have a number of structures where water drive is so high that we feel there should be 80 or 90 per cent. recovery. This also must be considered in arriving at the formula.

Too much weight can be given to such a table. In the hands of an unscrupulous engineer or royalty owner this table would cause any amount of litigation in this area. The royalty owner is concerned only with the number of barrels of oil produced per acre, and every operator has an obligation to the royalty owner to get the maximum economic recovery, and another obligation at law to get the maximum barrels per acre, and until you have more data and more knowledge of how these formulas are arrived at, it would be well not to give them too much prominence.

M. G. Cheney,† Coleman, Texas.—Do I understand, Dr. Haseman, that your calculations were based on the old Bartlesville field?

W. P. Haseman.—The only data that I have to support my formula are from publications of the U. S. Bureau of Mines.

M. G. Cheney.—The old Bartlesville fields which furnished these data were mostly produced with unrestricted open flow and wastage of gas under usual conditions of competitive drilling. No doubt individual wells widely spaced and favorably located in respect to oil, gas and water occurrence, with flow restricted by tapered tubing or otherwise to give a low oil-gas ratio would give entirely different results from average wells produced under the wasteful conditions which are the basis of Dr. Haseman's calculations. For example, I know one well in the Strawn sand, that 6 years ago came in for 600 bbl. This well was "pinched in" during its early life, has continued to flow and is still producing about one-third of its initial production with a total production to date of nearly 1,000,000 bbl. of oil, an amount to be expected from 10 to 20 wells under usual spacing. I wonder if the well-spacing data derived from antiquated methods of producing oil can be considered applicable to pools developed under the better methods of well management.

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* Director and Executive, Production Department, Humble Oil and Refining Co.
† President, Anzac Oil Corpn.

W. P. HASEMAN.—The formula will hold for any given method of development and operation. The existing field data should in general support the calculations recorded in Table 1 (*Natl. Petr. News*). The formula is equally applicable to pools where the expelling energy is directly associated with either the liquid or gas or both in the producing strata.

M. G. CHENEY.—The well referred to above produced as much alone as could be expected from 100 acres or more of Strawn sand, hence why drill 10 or 20 wells?

W. P. HASEMAN.—That is an exceptional case.

M. G. CHENEY.—It is an exceptional case in well management. There have been other cases where single wells producing without interference have yielded exceedingly large volumes of oil. Should we not investigate the possibilities of this profitable method of wide spacing and proper conservation of gas? Unit operation brings opportunity for testing such methods; *i. e.*, spacing wells far apart, shutting in wells with excess gas, maintaining high pressures by repressuring and so forth.

W. P. HASEMAN.—The spacing of wells is a problem of commercial pools only. A one-well pool is the exception and has no spacing problem.

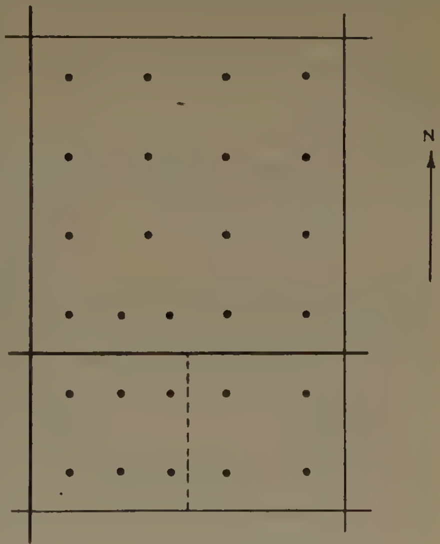

FIG. 1.

R. D. COPLEY,* Los Angeles, Calif.—Well spacing is one of the serious problems of the Los Angeles Basin. This is not due to the fact that we do not understand the fundamentals of economic spacing, but because all of the recent fields have had their "town-lot areas" or portions which have been previously subdivided for residential purposes. This permits the entree of many unscrupulous operators. One or more wells are drilled on lots of 50 by 150 ft. Naturally a large portion of the wells spaced so closely cannot hope to pay out, as the cost of drilling varies from about $60,000, in Torrance, to $175,000 in Santa Fe Springs. Under such conditions there is no incentive for operators to give adequate protection to sands other than those they expect to produce. Their only object is to reach the pay first and get the oil before their neighbors do.

There are many examples of the evils of town-lot drilling. Any one interested need only investigate the Lomita Area in the Torrance field, the town-lot areas in both the new and the old field at Huntington Beach, Alamitos Heights of the Seal Beach field, Los Cerritos area of Long Beach, or Hell's Half Acre at Santa Fe Springs, and compare these with the more orderly developed fields of Dominguez Hills, Inglewood or the easterly dome of Seal Beach field.

R. M. CARR,† Tulsa, Okla.—We have had occasion to observe a particular lease in the Seminole area. Some of the figures on it are very interesting. Let Fig. 1

* Production Department, Southern District, Standard Oil Co. of California.

† Petroleum Engineer, Sinclair Oil & Gas Co.

represent an 80-acre lease lying east and west. Due to a peculiar subdivision of royalty interests it was necessary to drill six wells on what would be equivalent to the west 40 acres, while the east 40 acres were drilled with the normal 10-acre spacing. I want to draw a few comparisons between the recovery per acre of the six-well 40-acre piece, the four-well 40-acre and also the offset 160-acre lease to the north.

The 160-acre lease was drilled with a normal 10-acre spacing except along the south line, where the owners naturally offset with five wells. Thus the lease has 17 wells.

The recovery per acre as of Aug. 1, 1929 on the six-well 40-acre was 57,500 bbl., on the 17-well 160-acre it was 45,750 bbl., while on the four-well 40-acre it was 41,000 bbl. even. The recovery per acre on the four-well 40 acres is very much in line with other offset leases drilled with 10-acre spacing. Probably a part of the higher per acre yield on the 17-well 160-acre piece is due to the additional well, although it may admit of some argument.

For comparison, without using lambda or anything but ordinary eighth grade arithmetic, I will attempt to prove that the 6⅔-acre spacing has been an advantage by producing more oil. Let us assume that the six-well 40-acre had been drilled with only four wells and that it was as productive as the 160 acres to the north, thus we could expect to produce only 45,750 bbl. per acre. The difference between the actual yield of 57,500 bbl. and the expected yield of 45,750 bbl. is 11,750 bbl. per acre. Multiplying by 40, we have a total difference of 470,00 bbl. If this additional 470,000 bbl. of oil has been recovered by reason of the two extra wells, let us carry the demonstration a little further and see what the additional recovery has amounted to in dollars. Deducting a one-eighth royalty of 58,750 bbl., we leave the producing company a net production of 411,250 bbl. from the two extra wells. The cost of the two wells was approximately $150,000. At $1 per barrel, net, for the oil, we have $411,250 minus $150,000 or $261,250 additional net return from the two wells.

Now, the six-well 40 acres could be compared to the four-well 40 with a greater difference in the figures. The west 27 acres of this 80-acre lease had four wells on it and the recovery of this 27 acres has been practically 70,000 bbl. per acre, notwithstanding the fact that one of the wells was greatly delayed in drilling. A comparison of these four wells with an average 40 acres of four wells having a recovery around 35,000 to 40,000 bbl. per acre is hardly justified, since it is too much like comparing individual wells.

I have not been advocating wider spacing and would take exception to the statement that one well to 20 acres will make more profit. One well to every 8 acres would have been an ideal spacing for the Seminole district. The best lease I know of in the Seminole field has a recovery of approximately 50,000 bbl. per acre, which is slightly higher than the per acres yield of this entire 80 acres we have been considering, but since the two leases are widely separated I doubt if a comparison should be made.

W. P. Haseman.—There is no doubt in my mind but that a closer spacing of wells in most of the commercial oil pools in this country would have yielded a greater profit per acre. There will be a quicker return of the well investment with closer spacing. For example, in the instance of the yield of 342,000 bbl. per well from the Bowlegs lease with the 10-acre spacing, there will be around 205,000 bbl. received within the first 100 days. With a spacing of 2½ acres per well there will be a yield of 184,000 bbl. per well with around 110,000 bbl. received within 110 days.

M. G. Cheney.—There must be other factors than well spacing involved to explain difference in yields. There is an extra 4500 bbl. per acre or a total of 720,000 bbl. on the 160-acre tract compared to the 40 acres southeast of it. The one extra well on the 160 acres can hardly account for the extra 720,000 bbl., hence

we must be dealing with some factors other than well spacing. As to extra yield due to six wells on the 40 acres, this case might be held to prove merely that if one operator completes six outlets to a high-pressure oil reservoir while practically all his neighbors complete only four, for his additional 50 per cent. drilling he will recover an additional 23 to 30 per cent. per acre. This seems to offer scant evidence that had this pool been drilled up with six wells to each 40 acres average yields would have been appreciably greater than under the customary plan of four wells per 40 acres.

R. M. Carr.—I believe I said something about the 17 wells on the 160 acres, leaving an opportunity for discussion. Even if it is not logical to attribute the additional production to the extra well, I would have chosen that 160-acre lease, because it shows the highest yield per acre outside this exceptional 40 acres I was demonstrating. I could have taken some other lease with a lower yield per acre and shown a greater proportionate net recovery from closer spacing.

M. G. Cheney.—If all surrounding 40's had the wells drilled at the same time and spacing, how much would have been gained per acre?

R. M. Carr.—They would undoubtedly have obtained more oil due to closer spacing. Practically a year elapsed before the sixth well was completed. Only four wells were producing during the flush stage, for the fifth well was delayed for some time. The sixth well has recovered only 94,000 bbl., yet this particular 40 acres is far above the average in total recovery.

W. V. Vietti,* Big Spring, Texas.—I have made a few calculations on the basis of Dr. Haseman's paper with particular reference to the figures he presents on the Bowlegs pool showing increased recovery and the increased returns expected per acre. These figures were analyzed from the point of view of making each additional well (drilled over the one well to 10 acre-tract) pay for itself.

Let us first consider the figures for 50 c. net oil—that is, the operator makes a gross of 50 c. on each barrel after deducting lifting costs, royalty, etc. One well to 10 acres will produce 342,000 bbl., or a return of $171,000 on a $100,000 well. This is, then, a profit of 71 per cent. Drilling two wells to the 10 acres or one well to 5 acres will increase the investment by $100,000; will increase the recovery by 205,200 bbl., and the gross return will be increased by $102,600. This, then, is a profit of $2,600 on the additional $100,000 invested, or a return of 2.6 per cent. Drilling one well to each 2½ acres will result, similarly, in a loss of $153,800 on the additional $300,000 invested for three additional wells on the 10 acres.

A different set of returns is obtained if the return will be $1 net for each barrel of oil. In this case, one well to 10 acres will produce a profit of $342,000; two wells to 10 acres will yield a profit of $105,200 on the additional well; but the 2½ acre spacing, or four wells to the 10 acres, will cause a loss of $7600 per additional well drilled.

We have worked out several well-spacing problems to determine proper spacing in new fields but always with the attitude of making a fair return on the additional investment necessary to space the wells closer than the one well to 10 acres.

* Petroleum Engineer, Continental Oil Co.

Spacing of Wells in the Long Beach Field

By Dwight C. Roberts and Stender Sweeney,* Los Angeles, Calif.

(Tulsa Meeting, October, 1929)

The spacing of wells in Long Beach oil field has caused much discussion from the earliest days of its development, on account of the closely drilled town-lot areas which have been as intensively developed as any productive areas in the world. The purpose of this paper is to present the results obtained from this type of development in comparison with the more widely spaced development in this field, now that a sufficient length of productive life has elapsed. The intensity of development in Long Beach is indicated by the fact that up to Sept. 1, 1929, there were 1736 wells either drilled or drilling. Of these 165 failed to get production and 121 were drilling. Thus 1450 wells have produced oil from an area of 1350 acres. Up to July 1, 1929, these wells produced a total of 355,047,913 barrels.

Method Pursued

Four groups of offset areas were chosen, in each group the wells in one area are widely spaced and in the other, closely spaced. The areas in each group are contiguous and the groups are spread over the field from the southeast end to the northwest, so that representative data are assured. The comparison has also been extended to shallow and deep zones, like zones in their respective areas being compared.

Even though these productive zones are very thick, a fair picture of results is obtained, because the drilling of the wells in the two types of areas was concurrent in the different groups and, as a rule, the thickness of sand opened up at any one time was about the same. As deeper sands were found, wells in offset areas were deepened or new ones were drilled in both types of areas. The division of zones was made in the same manner in contiguous areas.

The total cumulative production up to July 1, 1929, of the wells in their respective zones in each area was obtained. From these figures were computed the recovery per well, recovery per acre, acreage per well, and the ratios of these factors. Thus July 1, 1929, is the end of the period considered in all areas.

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* Superior Oil Corpn.

Data on Areas

Areas A and A′—Shallow Zone

These acres consist of 70 acres each, one of which has been drilled on a widely spaced program and the other very closely. These wells have been producing about 6 years.

In area A the average acreage per well is 2.92 while in A' it is 0.71. Thus it is apparent that the recovery per well has been greater in the more widely spaced area while the recovery per acre, and consequently the total recovery, has been greater in the closely drilled area. The proportions between these factors have been computed as shown in Table 1.

Table 1.—*Data on Areas*

Area	Number of Wells	Total Recovery, Barrels	Recovery per Well, Barrels	Recovery per Acre, Barrels	Ratio of Acreage per Well	Ratio of Recovery per Acre	Ratio of Recovery per Well
A	24	6,397,665	266,569	91,395	$A'/A = 1/4.08$	$A/'A = 1/2.15$	$A'/A = 1/1.89$
A'	98	13,759,127	140,399	196,558			
B	6	1,399,827	231,638	69,990	$B'/B = 1/4$	$B/B' = 1/3.98$	$B'/B = 1/1.02$
B'	24	5,471,061	227,961	273,553			
C^a	6	2,824,113	470,685	141,206	$C'/C = 1/3.83$	$C/C' = 1/1.28$	$C'/C = 1/2.99$
C'^a	23	3,621,756	157,468	181,088			
C^b	8	1,655,407	206,926	82,770	$C'/C = 1/2.5$	$C/C' = 1/1.43$	$C'/C = 1/1.67$
C'^b	20	2,760,981	138,050	138,050			
D	5	737,020	147,404	49,135	$D'/D = 1/3.4$	$D/D' = 1/3.17$	$D'/D = 1/1.07$
D'	17	2,335,581	137,387	155,705			

[a] Shallow zone.
[b] Deep zone.

This shows that four times as many wells have been drilled in A' as in A. The recovery per acre has been more than twice as great in the closely drilled area while the recovery per well has been slightly more than half as much.

Areas B and B′—Deep Zone

These consist of 20 acres each, which have been developed during the past year and a half. B is the wider spacing and B' is the town-lot spacing. In area B the average acreage per well is 3.33, while in B' it is 0.83. Thus there have been four times as many wells drilled in B' as in B. Up to the present time the wells in each area show an average recovery per well of about the same amount.

Four times as many deep-zone wells here have produced practically four times the amount of oil, but it must be borne in mind that the elapsed life of this production has been short and nearly all the wells are still in the flowing stage.

Areas C and C′—Shallow Zone

These two areas also consist of 20 acres each, C being the wider spaced. Production has been obtained from this zone in these areas for almost 7 years. Nearly all the development took place during their early life.

In area C the average acreage per well is 3.33. The productive life of those wells has been great enough to give a fair basis of comparison of two offset areas which are well along in the pumping stage on similar positions structurally, but developed on a radically different drilling program. Thus, somewhat less than four times as many wells have obtained about one-quarter more oil. However, the recovery per well has been three times as great on wider spacing with the attendant greater return per dollar invested.

Areas C and C′—Deep Zones

These are the same areas discussed in the preceding paragraphs, but attention is directed toward the results of deep-zone drilling, which started a little less than two years ago and continued concurrently in both areas. In area C the average acreage per well is 2.5 while in C' it is 1.

Even though these wells are in the earlier stage of their lives many have been on the pump or compressor for some time. Neither of these gives promise of reaching the production obtained from shallow zone wells in these same areas.

The wells drilled for the deep zone in the C area were more closely spaced than wells drilled for the shallow zone in the same area. At this period of their lives the deep wells show a greater proportionate recovery per acre than they do per well as compared to the shallow zone wells of this same area.

Areas D and D′—Deep Zone

These areas comprise 15 acres each, on which only deep zone production is compared here. The productive life considered has been about one year. The average acreage per well in D is 3.0 and in D' it is 0.88. Development in this area is more recent and consequently the productive life to date, shorter than in any other comparison which has been made.

These wells are practically all still flowing. They show over three times the production per acre from D' as from D up to the date considered. The recovery per acre of D' surpasses that of D, so that it is certain that with the present wells, D will not reach the closely drilled area in this respect.

Conclusion

Taking into account the size and shape of the areas chosen, their similarity geologically within each group, and their location in widely

separated parts of the field, it is felt that the above are representative comparisons and therefore legitimate to use for a few general conclusions.

In no case has the recovery per acre in widely spaced areas reached the recovery per acre in closely drilled areas. The difference between them is greatest during the early life and tends to decrease during the later years. This contention is further supported by the fact that wells in both types of development produce about the same amount per well during the flowing, or flush, stage which necessarily gives a greater acreage recovery during that period. *B-B′* and *D-D′* support this statement, whereas *C-C′* recovery per well shows considerable favor for the wider spaced area in the zone at present. However, this fact may be explained by the performance of the wells which have not been flowing long, so that a fair portion of the oil recovered has been derived after that period.

It is apparent that a greater yield of oil will be obtained from an area closely drilled than from a similar one with wide spacing. However, the economic return on the investment then becomes the governing factor to determine whether, under current market conditions, such additional expenditure is justified.

The conclusions in this paper are drawn from a study of a field of great thickness of highly productive oil sands. They should not be considered as applicable to a single, thin sand.

DISCUSSION

V. H. Wilhelm,* Los Angeles, Calif.—I regret that we have not gone into the differences of sedimentation. On the south side of the field, at the town-lot area, there is a great thickness of sand, and more ideal conditions than on top of the structure. Anyone who is familiar with the field can readily see that the field adapts itself to misinterpretation. It is rather unfortunate that those conclusions have been drawn without analyzing the differences in underground conditions in the field. The town-lot area on the south side is one of the most prolific areas in the Los Angeles basin, but its prolific nature is due mainly to underground conditions, not to being closely drilled. The paper will be wonderful propaganda for very close-spaced drilling.

S. C. Herold,† Los Angeles, Calif.—The paper shows clearly the fact that the Long Beach operator who gets there first, puts down the greatest number of holes, and produces the wells at the fastest rate, gets the greater quantity of oil from the reservoir. Every barrel of oil he produces means one less barrel for the other operators in the same zone; it is as if all were drawing from one great tank. While this situation holds for Long Beach and other fields which are in volumetric control, it does not hold in fields of capillary control. In the latter each well has its own drainage area independent of all other wells, regardless of the fact that production may all come from the same zone.

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† Petroleum Geologist.

Well Spacing in the Salt Creek Field

By F. E. Wood * Casper, Wyo.

(Tulsa Meeting, October, 1929)

This paper is written primarily as a discussion of Dr. W. P. Haseman's paper on "A Theory of Well Spacing"[1] and presents briefly the production records, and intensity and rate of development in a large portion of the two principal producing sands in the Salt Creek field, Wyoming. The study includes 1350 wells, 160,000,000 bbl. production, well spacings varying from two to seven wells per 40 acres and early and late development.

The general conclusions to be derived from this study are:

1. It is impossible to formulate a mathematical rule to apply to well spacing in the Salt Creek field.

2. Each tract is a separate problem.

3. Tracts first drilled produce the most oil, with many exceptions.

4. Initial production is not a reliable index to the relationship between past, current, or future production.

5. Wells which have produced the most oil in the past are not necessarily yielding the greatest current production nor will they yield the greatest future production. In fact, wells which have yielded the greatest past production will, in at least one-half the cases, make less oil currently or in the future than wells which have produced a smaller quantity of oil in the past.

6. The following is a safe rule to apply in well spacing in the Salt Creek field: (*a*) If the drilling of an additional well on a tract results in a sustained increased production, with prospects of making a profit, the tract is not overdeveloped and additional wells might be drilled. (*b*) If the drilling of an additional well does not effect a sustained increase in the production of a tract, the tract is fully developed.

Second Wall Creek Sand

The Second Wall Creek sand, covering 20,000 producing acres, is the principal producing horizon in the Salt Creek field; 1610 wells are producing at this time from this sand. This paper deals with but a portion of the entire field including 10,680 of the more productive acres,

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[1] See p. 146.

1061 wells and 125,000,000 bbl. of oil. Gas is almost the sole expulsive agent as there is no encroaching water.

The Second Wall Creek sand was first discovered in 1917. It was gradually developed until 1921 when 100 wells had been drilled with a potential production greater than pipe line capacity. Curtailment of production by mutual agreement of the operating companies was practiced from March, 1921, to December, 1923, at which later date the peak production of the field was reached and sufficient pipe line capacity had been provided to handle the potential production of the field. During the prorate period 350 wells had been completed. Intensive drilling was carried on in 1924, 1925, and 1926, during which time the total wells completed reached 1,606. Since 1926 a negligible number of wells have been completed to this sand.

In 1926, four wells were employed as key wells for repressuring. Each year additional wells have been added until at the present time 55 wells are used as input wells and are taking an average of 30,000,000 cu. ft. of gas per day. The gas drive has been most effective on the flanks of the structure. The natural gas-oil ratio has been too high on the crest of the structure to carry on a gas drive successfully. There are no key wells at the crest at this time.

The production from this horizon has been characterized by individual well performance. Some wells have produced in excess of 5,000,000 bbl. up to the first of this year, others have produced scarcely enough to pay for the drilling cost.

Production by Tracts

Table 1 shows the averages of the production of tracts grouped in accordance with the first year of development. Only tracts on the flank of the structure are included in order to give a fair comparison.

TABLE 1

Year of First Development	Wells	Average Initial Production per Well, Bbl.	Past Production per Well up to Jan. 1, 1929, Bbl.	Current Production per Well, 1928, Bbl.
1918	194	511	212,186	9,239
1919	30	324	104,549	1,979
1920	52	347	116,121	5,179
1921	242	377	108,597	9,291
1922	282	365	94,080	8,339

Table 1 is a general average and obscures many of the variations revealed by a closer study of the individual tracts involved. The figures indicate no definite relationship between initial production and past production or between initial and current production, or further

between past production and current production. It does show, however, that tracts which were drilled first produced the most oil up to the first of 1929.

Table 2 is a more detailed analysis of the same factors as shown above except that the element of well spacing has been added. Only those tracts showing equal development have been considered. Each quarter section included has been developed on the basis of 15 to 17 wells per 160 acres. There has been some variation in time of development. Two hundred fifty wells on 22 quarter sections are involved. The tracts are again grouped by years in accordance with the date of their first development.

TABLE 2

Year of First Development	Wells	Average Initial Production per Well, Bbl.	Past Production per Well up to Jan. 1, 1929, Bbl.	Current Production per Well, 1928, Bbl.
1918	110	625	263,172	9,098
1919	30	324	104,549	1,979
1920	52	347	116,121	5,179
1921	82	401	110,381	7,179
1922	76	352	91,434	8,350

Tracts First Drilled Produced Most Oil to Date

These figures indicate that there is very little, if any, relationship between intensity of development, initial production, total production to date, or production during 1928. In fact, in tracts first drilled in 1922, the last year on this table, the current production is 1200 bbl. per year greater than tracts first developed in 1921, or 2200 bbl. per year greater than tracts first developed in 1920, or 6000 bbl. per year greater than tracts first developed in 1919. There is one point evident, however. Tracts which were drilled first have produced the most oil to date, by far.

TABLE 3

Year of First Development	Past Production per Well up to Jan. 1, 1929, Bbl.		Difference, Per Cent.	Current Production per Well, 1928, Bbl.		Difference, Per Cent.
	High	Low		High	Low	
1918	290,000	63,000	78.3	17,200	3,500	79.6
1919	114,000	94,000	17.5	2,100	1,800	14.3
1920	193,000	114,000	40.9	6,500	4,900	24.6
1921	149,000	48,000	67.8	15,100	2,800	81.5
1922	159,000	60,000	62.3	14,900	4,700	68.5

The results of the gas drive have increased the production in areas where key wells are located but the average increase approximates only 10 per cent. and is not sufficient to make up the wide difference shown in the above figures. The effect of gas drive is compensating to a certain degree in that all but one of the tracts involved are enjoying effect of gas drive. The variation in production of the tracts making up these averages is very appreciable (Table 3).

Effect of Gas Drive on Production

There is too much variation in the figures in Table 3 to submit to an effective well-spacing formula. Each tract is a distinct problem and no other tract can be used as a criterion, let alone using any other field as a basis for computation of well spacing. This is better understood by a few representative comparisons. The figures for adjoining quarter sections are shown in Table 4. They are located identically from a structural standpoint and neither has ever been affected by gas drive.

TABLE 4

Tract	Average Years of Life per Well	Number of Wells	Average Initial Production per Well, Bbl.	Production per Well up to Jan. 1, 1929, Bbl.	Current Production per Well 1928, Bbl.
1	3.96	16	169	41,705	3,414
2	4.25	16	174	70,332	2,329

It will be noted that average life of wells, number of wells, and initials are closely similar and yet the past production per well has been vastly different, one tract having produced only 60 per cent. of the production of the other. Further, the tract which produced the greater quantity of oil up to Jan. 1, 1929, is producing currently only 68 per cent. of the current production of the tract which produced the smallest quantity of oil in the past. It is impossible to calculate mathematically a well-spacing formula which would apply to both tracts.

Another case, three adjoining quarter sections similarly located and all of which have been affected by gas drive, is shown in Table 5.

TABLE 5

Tract	Average Years of Life per Well	Number of Wells	Average Initial Production per Well, Bbl.	Production per Well to Jan. 1, 1929, Bbl.	Current Production per Well, 1928, Bbl.
1	4.04	16	447	96,462	3,121
2	4.26	17	491	149,707	15,139
3	4.02	16	499	132,778	11,207

Again the average age of wells, intensity of development and average initial production are very similar and yet there is a tremendous difference in the past and current production in these tracts. It should be stated in this case, however, that the tract with the smallest past and current production has been affected least by gas drive. The effect of gas drive, however, is but a small percentage of the difference shown in the figures in Table 5. This is another case of well spacing which it is impossible to interpret mathematically prior to complete development.

In another case we have two quarter sections similarly located with a like effect from gas drive. (Table 6.) Here, too, interpretation is impossible before complete development. The average life of the wells and development are almost the same. The initial production of the tracts vary and the one with the largest initial has produced and is producing but a small fraction of the amount of oil from the tract with the smaller average initial production. Such cases could be extended indefinitely.

TABLE 6

Tract	Average Years of Life per Well	Number of Wells	Average Initial Production per Well, Bbl.	Production per Well to Jan. 1, 1929, Bbl.	Current Production per Well, 1928, Bbl.
1	4.97	25	548	150,362	9,881
2	5.01	24	310	929,984	46,789

FIRST WALL CREEK SAND

The First Wall Creek sand, discovered in 1908, covered originally 4350 acres. Water encroachment has since reduced it to 3320 acres. This sand averages 120 ft. in thickness in the productive area and lies 900 ft. deep at the crest of the structure. This paper considers 3976 acres of the original area in which 293 wells have been drilled. These wells produced 36,000,000 bbl. of oil up to Jan. 1, 1929. Gas is the principal expulsive agent but a natural water drive also has been effective.

The sand is exceedingly erratic in character as may be shown in the following examples:

One well, drilled to a point near the bottom of the First Wall Creek sand, developed a crooked hole. No oil was encountered. The hole was filled back to the top of the sand and redrilled. The redrilled hole flowed an initial of 127 bbl. of oil per day.

One quarter section had been drilled with 14 wells in this horizon and had produced over 2,000,000 bbl. at the time when a well with a deeper sand as an objective encountered in this sand 2300 bbl. of flowing production. This is one of the largest wells drilled into this horizon and was completed 14 years after this quarter section had been first developed.

Fifteen years after the First Wall Creek sand was first developed a drilling campaign was started to deeper horizons. Many of the proposed wells formed twin locations to old First Wall Creek wells. Eight of these proposed deeper twin wells found oil in the First Wall Creek sand and were stopped to produce. The old First Sand wells at these twin locations averaged 43 bbl. at the time of the completion of the new wells. The initial production of the new wells averaged 206 bbl. or 163 bbl. greater than the average of the old wells which for years had supposedly drained the sand in their immediate area.

The first well on one quarter section was drilled in 1912 and has produced continuously ever since. This well's first peak year was in 1914 when it produced 82,891 bbl. Its second peak year was 11 years later in 1925 when it made 150,000 bbl. The following year (1926) it made 81,000 bbl. or as much as its flush peak year. Shooting was responsible for this later production. This quarter section in 1925 had seven wells drilled which were from 3 to 10 years old when the well referred to was shot. It is interesting to note that this quarter section reached its peak year in 1925, 13 years after the completion of its first well.

It would appear that drilling should continue in such a sand where there seem to be so many hidden reservoirs of oil undrained by existing wells. Careful analysis shows that the number of failures in prospecting for these prolific areas would offset the successful wells if this were the only producing sand. This difficulty has been overcome automatically by a drilling program to the deeper horizons. Wells encountering good production in the First sand are produced there.

In Table 7 are shown the averages of all quarter sections involved in this study. They are grouped according to the year of first development. In other words, the quarter sections developed first in 1908 are in one group, those first developed in 1910 in the next group, etc.

TABLE 7

Year of First Development	Number of Wells	Average Initial Production per Well, Bbl.	Total Past Production per Well to Jan. 1, 1929, Bbl.	Current Production per Well, 1928, Bbl.
1908	16	400	212,406	4,070
1910	38	241	163,766	3,428
1911	42	300	216,253	3,890
1912	157	247	87,000	5,157
1913	27	201	45,621	4,860

Table 7 indicates no relationship between initial production and production per well up to Jan. 1, 1929, nor does it show any relationship between initial production and current production. In fact, the

quarter sections having the smallest average initial production show next to the highest current production per well, although the average past production is but one-fifth of the greatest average past production per well.

DISCUSSION

H. H. Powers,* Tulsa, Okla.—Mr. Wood, in the Salt Creek field what in your opinion is the chief propulsive agent?

F. E. Wood.—In the First Wall Creek sand the propulsive agent is primarily gas although encroaching water is responsible for a portion of the oil produced. In the Second Wall Creek sand it is entirely gas. The productive area is surrounded by water, but water has not encroached.

J. W. Steele,† Casper, Wyo.—The data we have so far indicate that repressuring has been felt in the Salt Creek field over distances as far as 3000 ft. from the key wells, so that there are certain leases in the Salt Creek field where closer spacing than five wells to 40 acres is not necessary.

W. P. Haseman,‡ Oklahoma City, Okla.—The paper presented by Mr. Wood gives data which represent the initial and final conditions of producing properties. The data are largely unrelated facts and as such can not be used to verify or condemn any spacing formula. Since the data show a wide range in the yield of oil from the various properties it would be instructive to use one or more spacing formulas and compute the net profit per acre for various spacing of wells on those properties which gave the smaller acreage yield. Such a computation will probably give the maximum net profit per acre with a relatively close spacing.

S. Grinsfelder,§ Abilene, Texas.—It occurred to me that prior to the presentation of Mr. Wood's paper, the spacing of wells in the Salt Creek field would surely lend itself to some formula or system of spacing. This is suggested to anyone who is at all familiar with the uniformity of the characteristics of the producing sands in this field, but mainly the Second Wall Creek sand which has been the most prolific producing horizon.

In this case we have a field whose structure is a closed anticlinal fold embracing approximately 20,000 acres within the closure. The production in the Second Wall Creek sand covers the total amount of this acreage. A field having one producing sand member covering such a large area, suggests that more or less uniform conditions of development would exist and that the problem of well spacing would lend itself to some system.

The figures Mr. Wood has given are to the contrary and it is wondered if additional investigation of the data would not throw further light on the subject and even though one system would not apply to the whole field, certain areas of it would permit the application of a formula to the spacing of wells.

W. P. Haseman.—I would like to know whether there are any repressuring operations being carried on with a spacing of wells as wide as 10 acres per well that

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are profitable or give promise of being profitable. This inquiry is made because a fundamental study indicates that little or no profit can be secured from repressuring of old and depleted properties where the spacing of the wells is too wide.

F. E. Wood.—This paper has been prepared to give the conclusions of a great deal of detailed study in connection with the well spacing problem in the Salt Creek field. To make the paper readable much detail has been avoided.

This study has revealed wide differences in the decline curves of leases not only similarly located structurally but also drilled and produced under the same policies. The dissimilarities in decline curves suggest a great lack of uniformity in oil recoveries per well and per acre. The result has been widely different incomes from such similar leases. This study has definitely proved that maximum income as far as Salt Creek is concerned is not derived from close spacing of wells.

Equilateral Triangular System of Well Spacing

By C. S. Corbett,* New York, N. Y

(New York Meeting, February, 1930)

Early in the development of every oil field, the operators of relatively large tracts of land must decide upon a spacing plan for the wells to be drilled upon their respective tracts. Usually it is desirable to have a system of regular spacing laid out over the entire tract, making such adjustments as may be necessary near land boundaries.

Unless the dip of the producing formation is very steep, the equilateral triangular arrangement is the one most generally preferred, for the very good reason that it gives the maximum amount of drainage area for the wells up to the limit at which mutual drainage interference begins.

Assuming that the equilateral triangular pattern is to be used, there still remains to be decided the matter of distance between wells. Many variable factors enter into the problem of proper spacing, some of which are physical and some economic. It is not the purpose of this paper to discuss these factors, as that has been done in several comprehensive articles during the past few years. In the end the decision must be based upon an estimate of the relative importance of various factors which apply to the field in question and to economic conditions in the oil industry at the time the development is getting under way. Even if the best possible spacing distance should be chosen when the problem arises, changing economic conditions and variation in physical conditions in different parts of the field may cause the original choice to become more or less unsatisfactory.

Obviously, it is advantageous, once a spacing plan has been adopted, to avoid alteration of it as the field becomes better known or as conditions in the industry change, and yet be able to vary somewhat the acreage per well in extending the area of development. Or, it may be desired to provide for an ultimate spacing considerably closer than conditions seem to warrant early in the development of the field. With these contingencies in mind, it is of interest to examine the possibilities which the equilateral triangular system affords.

Orientation of Coordinate System

In this system the well locations may be considered as the inersectionst of three sets of coordinate lines, the lines of each set intersecting those of the other two sets at 60°. For convenience in placing such a system

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on a well location map, one of the three sets of lines may be dropped. The remaining two sets form a 60° coordinate system entirely adequate for laying out and designating the well locations. In fact the equilateral triangular system could just as suitably be designated the "60° coordinate system." In such a system the areas bounded by the coordinate lines are diamond-shaped and each diamond is, in fact, the equivalent of two contiguous equilateral triangles. If the shorter diagonal of one of these diamonds is taken as unity, the longer one equals $\sqrt{3}$ or 1.732. The shorter diagonal is the spacing distance of the system, being equal in length to the sides of the diamonds.

In placing such a coordinate network over an oil-producing structure it would seem advisable, unless the dips are in general quite steep, to orient it so that the shorter diagonals of the diamonds are parallel with the principal direction of strike. For example, in the case of an anticline or an elongate dome, the shorter diagonals should parallel the axis of the structure, thereby affording a spacing of wells closer along the strike than in the direction of dip over most of the structure, providing all of the locations are drilled. This is desired as movement of oil in the formation under the influence of gas or water drive is predominantly normal to the strike.

Spacing Distance Ratios

But the ratio of distance in the oil-bearing horizon ("formation distance") to map distance in the direction of dip increases as the

TABLE 1.—*Ratio of Formation Distance between Wells*

Orientation: Diagonal of Diamond Parallel to Strike	Angle of Dip, Deg.	Formation Distance Ratio: Direction of Dip / Direction of Strike
Shorter diagonal	30	2.0*
Shorter diagonal	46	2.5
Shorter diagonal	55	3.0
Longer diagonal	55	1.0
Longer diagonal	70	1.7
Longer diagonal	76½	2.5
Longer diagonal	78¾	3.0

* To indicate more fully what this ratio means, the first instance is outlined here in more detail. For the given orientation, the *map distance* between wells in the direction of dip is 1.732 times the map distance in the direction of strike. For a 30° dip, the ratio of formation distance to map distance in the direction of dip is 1.15 (from curve of Fig. 1). In the direction of strike this ratio is of course always 1. Multiplying the two ratios (1.732 × 1.15), the result is 2, which therefore expresses the fact that, for the given orientation and a dip of 30°, the formation distance between wells in the direction of dip is two times the formation distance between wells in the direction of strike.

secant of the angle of dip. It is shown by the curve in Fig. 1 for angles of dip up to 79°.

Table 1 shows the ratios of the *formation distance* between wells in the direction of dip and in the direction of strike for certain indicated orientations of the 60° coordinate system and for certain angles of dip.

Taking into account the characteristics of each field, it is, of course, a matter of opinion as to angle of dip at which it becomes desirable to orient the coordinate system so that the shorter diagonals of the diamonds

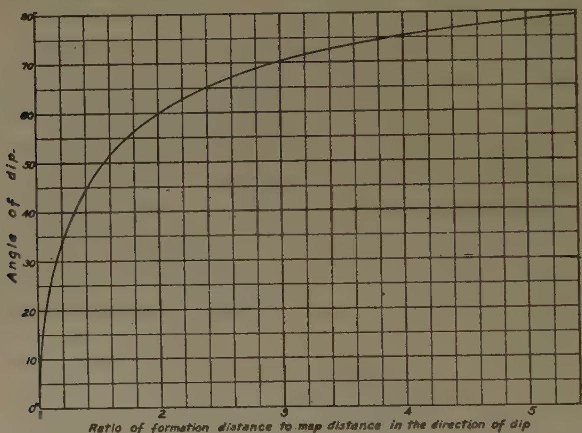

FIG. 1.—SECANT CURVE SHOWING RATIO FORMATION DISTANCE/MAP DISTANCE IN DIRECTION OF DIP, FOR ANGLES OF DIP UP TO 79°.

will be normal to rather than parallel to the principal direction of strike. In general, a spacing distance *in the formation* 2½ to 3 times as far between wells in the direction of dip as in the direction of strike, corresponding respectively to dips of 46° and 55°, would seem to be about as high as this ratio should be carried. For the other orientation (shorter diagonals normal to the strike) it is only for dips as steep as 55° that the spacing distance in the formation would be as great between wells in the direction of dip as in the direction of strike. Consequently, if the dip throughout most of the field is steeper than 55°, the orientation of the well spacing coordinate system would probably best be made with the shorter diagonals of the diamonds normal to the principal direction of strike, assuming that eventually all the locations provided by the system will be drilled.

If the dip is steeper than approximately 75°, it would probably be advisable to modify the coordinate system so as to bring the formation distance between wells in the direction of dip within about 2½ times the distance in the direction of strike, since, under the orientation of the equilateral triangular system last mentioned the formation spacing in the direction of dip becomes 2½ times the spacing in the direction of

strike when the angle of dip reaches 76.5.° This again is arbitrary. A small change in the angle of dip when that angle is more than 70° results in a relatively large change in the spacing ratio. This is brought out forcibly by a comparison of the figures in the last three lines of the above table.

In connection with the matter of orientation of the equilateral triangular location system, it is interesting to note that only a 30° change in strike (or in orientation) is necessary to reverse the relationship between the well spacing (map distance) in the directions of strike and dip. This is obvious from the fact that the angles of an equilateral triangle are 60° angles. However, it is not obvious to the eye when only two sets of coordinate lines are used unless they are so chosen that the two positions of orientation appear to be 90° apart.

Various Methods of Selecting Locations

The remainder of the discussion deals mainly with the use of the 60° coordinate system as oriented for fields of gentle to moderate dips and the various ways of selecting locations for drilling when every site provided for by the system is not to be drilled, at least not at the start.

For illustration, we may assume that we have an oil-bearing anticline of gentle to moderate dips in which, on account of high grade oil, fine-grained sands, and shallow depth to the sands, with attendant low drilling costs, it will probably be found desirable to space the wells only 100 meters apart over much or all of the productive area. A 60° coordinate system providing for well locations 100 meters apart in an equilateral triangular arrangement, is placed over the field, oriented so that the shorter diagonal of the diamond pattern is parallel to the axis of the anticline. If completely drilled there would be one well to 2.14 acres.

There are ways of choosing locations on this coordinate system further apart than 100 meters, by which a regularity in spacing may be maintained that should be productive of very satisfactory results even if a smaller number of locations is drilled than the total provided for by the coordinate system. The most obvious way is that of simply selecting alternate locations on alternate coordinate lines as shown in Fig. 2. In this case only one-fourth of all the locations would be drilled, the wells having an equilateral triangular spacing 200 meters apart. There would be one well to 8.56 acres. The spacing would be 346.4 meters (map distance) between wells in the general direction of dip and 200 meters in the direction of strike.

One-third of all the locations could be drilled and an equilateral triangular arrangement of the wells maintained if the locations were selected as shown in Fig. 3. The wells would be drilled 173.2 meters apart. There would be one well to each 6.42 acres. The spacing would be 173.2 meters (map distance) between wells in the general direction of

dip and 300 meters in the direction of strike. This arrangement virtually amounts to using a second 60° coordinate system having a somewhat wider spacing of lines (shown as dashed lines in the drawing) and an orientation at right angles to the coordinate system over which it is

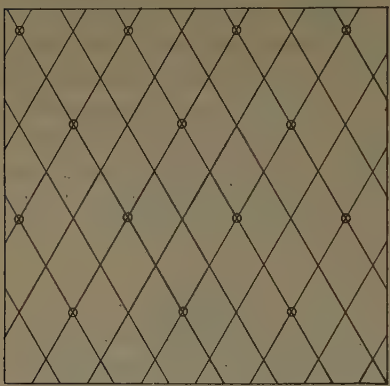

FIG. 2.—SELECTION OF ONE-FOURTH OF WELL LOCATIONS PROVIDED BY A 60° COORDINATE GRID, WITH MAINTENANCE OF EQUILATERAL TRIANGULAR SPACING ARRANGEMENT.

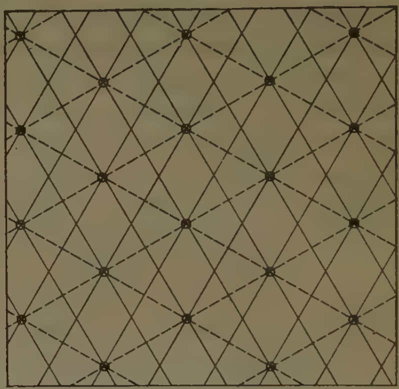

FIG. 3.—SELECTION OF ONE-THIRD OF WELL LOCATIONS PROVIDED BY A 60° COORDINATE GRID, WITH MAINTENANCE OF EQUILATERAL TRIANGULAR SPACING ARRANGEMENT.

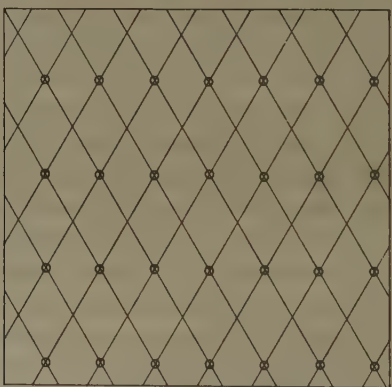

FIG. 4.—SELECTION OF ONE-HALF OF WELL LOCATIONS OF A 60° COORDINATE GRID, WITH RECTANGULAR SPACING ARRANGEMENT.

superimposed. Its only drawback is this orientation, whereby the wells would be spaced closer in the general direction of dip than in the direction of strike. If it appeared reasonably certain that, over most of the field, only one-third of all the locations of the 100-meter system would be drilled, it would probably be advisable to change the orientation so that the wells drilled on the 173.2 meter spacing would be farther apart in the direction of the dip than in the direction of strike.

Should it be desired to drill one-half of all the locations, the method of selection shown in Fig. 4 would doubtless be the best one. Here the wells would have a rectangular rather than an equilateral triangular arrangement and would be spaced 173.2 meters (map distance) in the general direction of dip and 100 meters in the direction of strike. There would be one well to 4.28 acres.

Thus, it is possible to drill one-third or one-fourth of the locations provided for by a given 60° coordinate system for well locations and yet maintain equilateral triangular spacing. Such an arrangement cannot be maintained in drilling one-half of the locations. If that is desired, the preferable manner of selection would seem to be the rectangular arrangement shown in Fig. 4, in which, for average dips of 55° or less, the greater distance between wells is in the direction of dip. For average dips greater than 55°, the same rectangular manner of selection may be followed but orientation of the coordinate system should be at right angles to the orientation used for gentler average dip.

Input Wells for Repressuring a Depleted Field

Another feature of the equilateral triangular spacing arrangement is the advantage it affords in the selection of input wells for gas in repressuring a depleted field.[1]

If every location provided for by the 60° coordinate system has been drilled, one-third of the wells can be chosen for the return of gas according to the method shown in Fig. 3. By analogy with the term "five-spot," applied to wells used for gas input each of which serves four wells in a square arrangement, each input well in this case may then be termed a "seven-spot" well, since it serves six wells in a hexagonal arrangement, all six of which are equidistant from it.

In the five-spot plan, one-half of all the wells are required for input of gas in contrast to only one-third of the wells being so required in the seven-spot plan. By the latter method each producing well is in turn served by three input wells equidistant from it, in contrast to four equidistant input wells in the five-spot arrangement. In this respect, there may seem to be some loss in effectiveness for the seven-spot input well as compared with the five-spot but such loss can hardly offset the gain resulting, in the seven-spot arrangement, from the maintenance of a larger percentage of the wells as producers.

[1] The writer has recently attempted to show that, in unit operation, reservoir pressure should be maintained by return of all excess gas through wells at the crest. (See p. 128.) In fields operated on a competitive basis this procedure is not feasible and it becomes necessary for each producer to conduct his repressuring operations more or less independently, cooperating perhaps with his neighbors along the boundaries of his lease.

Chapter III. Gas-oil Ratios

Quantitative Effect of Gas-oil Ratios on Decline of Average Rock Pressure

By Stewart Coleman,* H. D. Wilde, Jr.,† and Thomas W. Moore,‡
Houston, Texas

(Tulsa Meeting, October, 1929)

It is recognized that in the early days of the petroleum industry oil was produced with practically no scientific or fundamental knowledge of the laws and principles governing its extraction from the ground. Only a few, if any, of those exploiting the oil resources made any effort to collect accurate scientific information. There was little need for it, for as is frequently the case where the supply of a natural resource appears inexhaustible and is greater than the demand, large profits were possible from merely skimming the surface with little regard to the efficiency or thoroughness with which the oil was obtained. With this policy in force, great quantities of gas were wasted and when the reservoirs ceased producing by natural means they still contained a large fraction of the oil originally in them.

The present tendency in the industry is toward conserving existing oil reserves. In order that greater percentages of the oil present in the ground may be recovered, efforts are being made to improve production methods and to rework depleted fields. If the production methods are to be improved intelligently it is essential that the fundamental laws be known and understood, consequently large amounts of money and effort are being spent in gathering data that will serve to define and interpret these laws.

A great deal of attention is being focussed on the study of the motion of oil through an oil-bearing sand, the forces that cause it to move and the factors that affect its motion. It is recognized that one of the important factors is pressure, but its quantitative effect is not known. In a given field the rate of production declines with time and so does the rock pressure. Furthermore, a comparison of different fields shows, as a

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rule, that those with the greater initial rock pressure[1] have the greater initial production. This leads naturally to the conclusion that the production rate is roughly proportional to the rock pressure and it is plausible to assume that if steps be taken to make the rock pressure decline more slowly than it would under natural operating conditions the production rate will decline less rapidly. If this is so, the ultimate recovery under these conditions should be greater. Quantitative evidence concerning the effect of pressure maintenance on the rate of production is lacking but it is hoped that future investigations will show what it is.

There are two methods by which the decline of rock pressure can be retarded: (1) by controlling production of the oil in such a manner that the amount of gas removed from the reservoir with a given amount of oil is low, for the lower the gas-oil ratio, the more slowly the pressure will decline; (2) by returning to the oil-bearing reservoir all or a portion of the gas that is brought to the surface with the oil, which is equivalent to a reduction of the gas-oil ratio equal to the difference between the total gross gas produced and that returned.

It is of considerable value to know quantitatively what change in the decline of rock pressure would result from a change in the gas-oil ratio. With such a relation it would be possible to predict the change in rock pressures with various production methods. It would show, for instance, what rock pressures could be expected if a program of repressuring in the early life of the field were made effective and how great a fraction of the oil could be produced before the rock pressure would fall to a given value. This information would serve as a basis for estimating future increased production to be expected from an early repressuring project.

Inasmuch as a naturally flowing well will continue to flow as long as the pressure at the bottom of the well is sufficiently great, maintenance of rock pressure at a high level should lengthen the flowing life of a field. Since lifting costs in pumping wells will average 25 c. per barrel, the economic value of maintaining a high rock pressure is manifest. Pressure maintenance might be justified from this point of view even if there were no increase in the total oil recovered. To establish the relation between gas wastage and rock pressure would be essential in making an economic balance between the cost of gas injection and the saving of lifting costs, and would determine whether the cost of a proposed project of early repressuring would be justified on the basis of saving in lifting costs alone.

This paper presents one derivation of a mathematical relation between the amount of gas wasted from the reservoir and the average rock pressure after a given fraction of the oil has been removed.

[1] By rock pressure is meant the average pressure throughout the field, both at the wells and the areas between the wells.

Derivation of Equation

The only assumptions necessary in the derivation of this equation are: (1) that there is no water drive; (2) that the solubility of the gas in the oil follows Henry's law; *i. e.*, the volume of gas (measured at standard conditions) dissolved in a unit volume of gas-free oil is directly proportional to the gas pressure. This last assumption is justified by the work of Beecher and Parkhurst, Dow and Calkin, Mills and Heithecker, and others, who have found a linear relation between the pressure and the amount of gas dissolved. Certain terms used in this paper are defined as follows:

Gas-free oil is dead oil resulting when the pressure is reduced to zero pounds gage; in other words, it is oil saturated with gas at one atmosphere.

Original conditions are the conditions of pressure, temperature, sand saturation, etc., existing in the reservoir just prior to the time the first well is drilled.

Volume of the reservoir is understood to mean the total volume of all the pore space in the sand.

x is the fraction of the gas-free oil originally in the reservoir that has been removed up to a given time. The gas-free oil originally in the sand is therefore equal to 1.

P is the original rock pressure expressed in atmospheres.

p is the mean rock pressure in the reservoir after a given fraction of the oil, x, has been removed. This is also expressed in atmospheres.

k is the constant in the expression for Henry's law; amount of gas dissolved $= kp$.

a is coefficient of volume expansion due to the solution of one unit of gas in one unit of gas-free oil. Thus the total volume occupied by the mixture of oil and gas when one volume of gas-free oil is saturated with gas under the pressure p is $(1 + akp)$.

y is the fraction of the total gas originally in the reservoir wasted in producing x volumes of oil. When gas is returned to the reservoir, only the difference between the total gas produced and that returned is considered as wasted.

m is the ratio of volume of reservoir filled with free gas at pressure P to the volume filled with oil.

g is the mean amount of gas wasted with each unit of gas-free oil produced, divided by the total amount of gas in the reservoir per unit of oil under the original conditions. Therefore, $y = gx$. If r is the mean gas-oil ratio (cubic feet of gas per cubic foot of oil) during production.

$$g = \frac{r}{mP(1 + akP) + kP}$$

In the derivation to follow, all volumes are expressed in cubic feet. Volumes of the gas-free oil, the total liquid and the space in the reservoir,

being independent of the pressure, are expressed in cubic feet and are not corrected for pressure. But all volumes of gas are expressed as the number of cubic feet the gas would occupy at one atmosphere of pressure and the reservoir temperature.

As all volumes, whether of the liquid, gas, or space in the reservoir at any time, will be expressed in terms of a fraction of the gas-free oil originally present, it is immaterial, for the purposes of the derivation, how much oil is originally present in the reservoir.

In order to simplify the mathematics of the derivation, it is assumed that the reservoir originally contains 1 cu. ft. of gas-free oil. The relation thus derived may be applied to any given reservoir, for the rock pressure after one-half the oil is removed under a given set of conditions is the same whether the oil originally contained in the reservoir was 1 cu. ft. or any multiple of that amount.

The volume of the gas-free oil at the start is equal to 1; of the liquid is $(1 + akP)$; and of the free gas is $m(1 + akP)$. The total volume of the reservoir is the sum of the last two or $(1 + akP) + m(1 + akP)$.

After x volumes of gas-free oil have been removed from the reservoir:

$(1 - x)$ = volume of gas-free oil remaining in the reservoir.

$(1 - x)(1 + akp)$ = volume of liquid remaining in the reservoir.

The volume of the free-gas space in the reservoir will be equal to the total volume of the reservoir minus the volume of the liquid or $[(1 + akP) + m(1 + akP)] - (1 - x)(1 + akp)$, which is equal to $x(1 + akp) + ak(P + Pm - p) + m$.

$(1 - x)kp$ = volume of gas dissolved in the saturated oil remaining in the reservoir (measured at atmospheric pressure and the reservoir temperature).

The total volume of gas (measured at atmospheric pressure and reservoir temperature) remaining in the reservoir will be equal to the sum of gas dissolved in the oil plus the gas occupying the free-gas space in the reservoir, so

$(1 - x)kp + p[(1 + akp)x + ak(P + Pm - p) + m]$ = total volume of gas remaining in the reservoir.

The volume of gas remaining in the reservoir may be expressed in another manner, for since the volume of gas dissolved in 1 cu. ft. of gas-free oil under original conditions is kP and the volume of free gas associated with it is $Pm(1 + akP)$, and as y(or gx) is the fraction of this gas which has been wasted,

$(1 - y)[(1 + akP)\,Pm + kP]$ = volume of gas remaining in the reservoir

Equating these two expressions we have,

$$\begin{aligned}(1 - x)kp + p[(1 + kp)x + ak(P + Pm - p) + m]& \\ &= (1 - y)[(1 + akP)Pm + kP] \\ &= (1 - gx)[(1 + akP)Pm + kP]\end{aligned}$$

For a given field a, k, m and P are fixed and when g is set at any desired value the only variables are p, the rock pressure, and x, the fraction of the oil produced. The natural procedure in using this equation would be to assign a value to x and solve for p, but since the equation is a quadratic in p and only linear in x, it is simpler to express x in terms of p. Thus expressed the equation becomes

$$x = \frac{m(P + akP^2 - akpP - p) + k(P - p - apP + ap^2)}{m(gP + gakP^2) + (1 - k)p + akp^2 + gkP} \qquad [1]$$

For a field where all the gas in the reservoir is held in solution (where there is no free gas), m becomes equal to zero. This simplifies the above equation to

$$x = \frac{k(P - p - apP + ap^2)}{(1 - k)p + akp^2 + gkP} \qquad [2]$$

Numerical Illustrations

The manner in which these equations can be used is best illustrated by means of numerical examples. A hypothetical case will be used but the conditions assumed will not differ materially from those existing in an actual field. Consider an oil field under the following conditions:

1. The original rock pressure P is 100 atm. (1470 lb. per sq. in.).

2. At 100 atm. and the reservoir temperature, 240 cu. ft. of gas is dissolved per barrel of gas-free oil, giving a solubility of 42.6 cu. ft. of gas per cubic foot of oil. In this case, $k = 0.426$ cu. ft. of gas (at standard conditions) dissolved per cubic foot of oil per atmosphere of pressure.

3. When saturated with gas at 100 atm., the volume of the mixture is 10 per cent. greater than the volume of the gas-free oil. Therefore, $a = 0.00234$.

4. The porosity of the sand is uniform throughout and has a normal value, so the sand is "open." The formation is not lenticular but forms a single reservoir. The wells are evenly spaced so that the same average rock pressure exists in the various portions of the reservoir.

Case 1. *10 Per Cent. Free Gas in Reservoir at Start and All Gas Produced Returned to Reservoir*

For these conditions $m = 1/9$, as volume of free-gas voids is 10 per cent. and volume of oil-filled voids is 90 per cent. Since no gas is wasted, $g = 0$.

Substituting values of a, k, P, m, and g in equation 1, we have

$$x = \frac{54.5 - 0.645p + 0.001p^2}{0.577p + 0.001p^2 + 0}$$

Curve 1 (Fig. 1) is plotted from this equation. In this chart the values of p found from the equation have been multiplied by 14.7 in order to express the pressures in pounds per square inch.

Case 2. No Free Gas at Start and All Gas Returned to Reservoir

In this case $m = 0; g = 0$.

Substituting values of a, k, P, and g in equation 2 we have

$$x = \frac{42.6 - 0.523p + 0.001p^2}{0.577p + 0.001p^2 + 0}$$

Curve 2 is plotted from this equation.

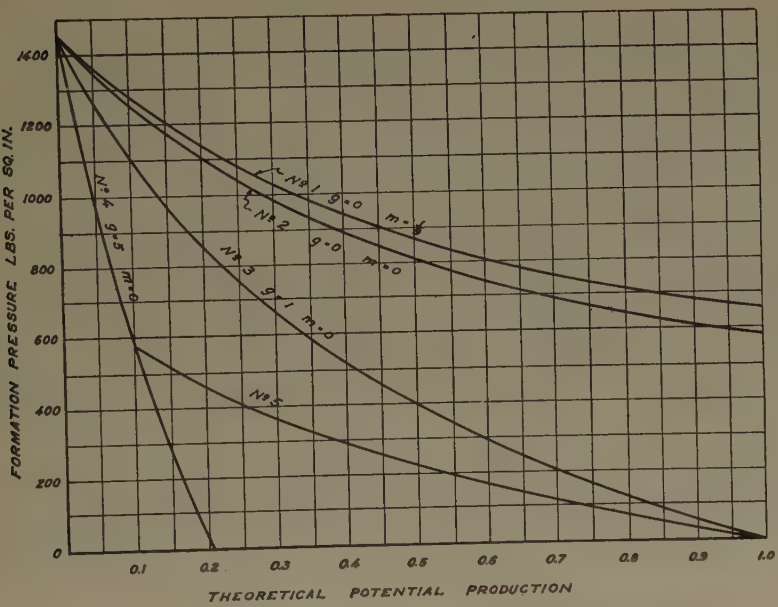

FIG. 1.—CURVES PLOTTED FROM AUTHOR'S EQUATION.

Case 3. No Free Gas at Start and Gas Wasted Equal to Original Solubility

In this case $m = 0; g = 1$. The mean gas-oil ratio during production is 240 cu. ft. per barrel of oil.

Substituting values of a, k, P and g in equation 2 we have

$$x = \frac{42.6 - 0.523p + 0.001p^2}{0.557p + 0.001p^2 + 42.6}$$

Curve 3 is plotted from this equation.

Case 4. No Free Gas at Start and Gas Wasted Equal to Five Times Original Solubility

In this case $g = 5; m = 0$. This is equivalent to an average gas-oil ratio of 1200 cu. ft. per barrel of oil.

Substituting values of a, k, P and g in equation 2 we have,

$$x = \frac{42.6 - 0.523p + 0.001p^2}{0.577p + 0.001p^2 + 211.5}$$

Curve 4 is plotted from this equation.

Case 5. Gas Wastage Changed during Production

The four examples cited apply to conditions where a given average gas-oil ratio prevails from the beginning of production to the point in question. There are many cases to be considered where one ratio prevails for a part of the time and thereafter the ratio is changed decidedly; for example, where repressuring is started after the field has produced oil in the normal manner. In this case a curve should be drawn representing conditions up to the time of the change. The value of p at the time of the change becomes P for a new equation and the new m can be calculated from the original value of m and the value of x. The new values of x calculated from this second equation will be expressed as fractions of the oil in the reservoir at the time the change is made and not of the oil originally in the reservoir. It is an easy matter, however, to convert these values of x into a set expressed in terms of the original oil content of the reservoir. The following calculation illustrates a case described above.

Assume that the conditions represented by curve 4 held until the pressure falls to 590 lb. (40 atm.). By this time 0.095 or 9.5 per cent. of the gas-free oil has been produced. At this point repressuring is started with the result that net gas-oil ratio drops from 1200 to 140 cu. ft. per barrel.

Computation will show that when the repressuring is started, there is a ratio of 140 cu. ft. of gas to each barrel of oil left, and, therefore, for the new equation, $g = 1$. Since m is defined as the ratio of the reservoir space occupied by free gas to that occupied by liquid

$$m = \frac{(1 + akP) - (1 - x)(1 + akp)}{(1 - x)(1 + akp)}$$

Substituting 40 for p, and 0.095 for x, m comes out equal to 0.164.

Using $k = 0.423$, $a = 0.00234$, $P = 40$, $m = 0.164$, and $g = 1$, a pressure-decline curve can be calculated. The results of such a calculation, expressing x in terms of the oil originally present, are plotted as curve 5.

Practical Applications

The relation between the gas wastage in a given field and the decline of the rock pressure can serve as the basis for a number of important calculations. Several of the applications will be discussed briefly.

Using this equation, curves can be drawn to show the relation between the gas-oil ratio and the rate at which rock pressure in a reservoir declines. For example, curve 2 represents a case where all of the gas is returned to the reservoir and the net gas-oil ratio is consequently zero. This curve shows that returning all of the gas does not maintain the pressure at its original value, as is sometimes supposed, but that the pressure will gradually decline. If it were possible to remove all the oil, the pressure would finally fall to 564 lb., which is 38.4 per cent. of the original rock pressure. The rock pressure after any given fraction of the oil has been produced can be predicted from this curve.

Curve 3 is for a case where the original reservoir conditions are the same as for curve 2, but the net gas-oil ratio, or the gas wasted, is equal to the gas originally dissolved in the oil. For the assumed field, it is a ratio of 240 cu. ft. per barrel. Nere the pressure declines much more rapidly than for curve 2, and the pressure will fall to atmospheric at the time all the oil is removed.

Curve 4 is similar to the other two except that the net gas-oil ratio is fivefold the original solubility, or 1200 cu. ft. per barrel. In this case the pressure declines rapidly, reaching atmospheric when only 20 per cent. of the oil has been produced. Similar curves could be drawn to illustrate other ratios, but these should suffice, as they clearly indicate the trend.

This equation can be used to illustrate the marked effect that small increases in the gas-oil ratio have on the maximum amount of oil recoverable and to point out the importance of keeping the gas-oil ratios at the lowest possible value. Table 1 is calculated for a reservoir under these conditions.

TABLE 1.—*Effect of Small Increases in Gas-oil Ratio*

Average Gas-oil Ratio	g	Value of x when p becomes Zero
240	1.0	1.00
360	1.5	0.67
480	2.0	0.50
720	3.0	0.33
960	4.0	0.25
1200	5.0	0.20
1800	7.5	0.13

It is evident that the values in the third column are reciprocals of g.

It must not be inferred from this table that if the indicated gas-oil ratios prevail, it is possible to produce the corresponding amounts of oil given in the third column. If it is granted that gas energy is the

force that moves the oil to the well, there must be pressures in the reservoir greater than at the bottom of the well, if there is to be any movement of oil to the well and the average pressure over the field, p, will be greater than zero. The exact value of the mean rock pressure when production ceases will probably vary from field to field, depending on the conditions in the oil-bearing reservoir, and it is doubtful whether anyone at present knows what this value is. Production will cease before p falls to zero and consequently before x reaches the value shown. However, it can be stated definitely that where the oil movement is due to gas energy, with a given gas-oil ratio, the total production cannot exceed the values given.

For fields that have been developed in the past under competitive conditions with little attempt to control the gas-oil ratio, it can be estimated that the mean gas-oil ratio has been between 1200 and 2000 cu. ft. per barrel, giving values of g between 5 and 6, so that the maximum recovery possible is limited to 16 to 20 per cent. This estimate agrees with those commonly made for the recovery from such fields.

It is evident from this table that the gas-oil ratio should be kept as low as possible in order that the production limit may be as large as possible. When the gas-oil ratio is not large, even small changes in the ratio affect the limit considerably. Thus, if the ratio is 480 cu. ft. per barrel, the limit is 50 per cent., and an increase of only 240 cu. ft., bringing the total to 720, will reduce the limit from 50 to 33 per cent. In a large pool, this can mean a difference of several million barrels. In some fields the ratios can be kept low, but in many the ratios, unfortunately, are high. In June, 1929, four California fields had average ratios varying between 1200 and 4600 cu. ft. and one field had an average ratio of 23,000 cu. ft. per barrel. Unless an unusually large portion of the reservoir is filled with free gas, these ratios point to a low percentage of ultimate recovery. As the crude produced in the field in which the ratio of 23,000 cu. ft. per barrel prevails has a high gravity, the solubility of the gas is undoubtedly large. But even if the solubility is as high as 600 cu. ft. per barrel under the original pressure conditions, and if it is assumed that one-third of the reservoir is filled with free gas, the rock pressure will fall to zero when less than 3 per cent. of the oil is produced.

The curves indicate that if, as a result of returning to the reservoir a portion of the gas produced, the value of g is less than 1, p will never fall to zero. This should not be interpreted to mean that 100 per cent. of the oil can be recovered. This is not necessarily so, for it will probably happen that as the reservoir becomes depleted, more and more gas will accompany a barrel of oil to the well and as this gas is returned a cycle will be established. Even under pressure, the daily production rate will probably become small as the reservoir approaches complete depletion, and a point will be reached before the reservoir is entirely

empty at which the rate of oil production will be so low that it will not pay to compress the gas necessary to continue production from the field. At what point this economic limit will be reached cannot be predicted, but it seems reasonable to suppose that it will be somewhere between 60 and 80 per cent. This limit is so much greater than those corresponding to normal production methods that it emphasizes the importance of returning all gas possible from the very start.

Although at the present time we are unable to predict how the daily production rate in a particular field will be affected by the mean rock pressure and the extent to which the pore spaces of the sand in the reservoir have been depleted of their liquid content, it is hoped that future research work will reveal such a relation. If anyone is fortunate enough to discover this relation, the equation and the curves described in this paper will be useful in calculating the pressures needed in the expression used for predicting rates of production.

A knowledge of the volume of oil contained in a given reservoir is always valuable. If the initial rock pressure, the present average rock pressure, the solubility of the gas and the average gas-oil ratio prevailing up to the present are known, the fraction of the oil which has been produced can be calculated from this equation. If the total oil production up to the present is known, the total amount of oil in the ground can be readily calculated. For example, suppose the original conditions in the field are the same as those assumed in the illustrations given, that the oil is produced with a ratio of 1200 cu. ft. per barrel, and that 2,000,000 bbl. of oil have been produced by the time the pressure falls to 1030 lb. (70 atm.). In this case curve 4 would apply, indicating that 0.04 of the total amount of the oil originally in the reservoir has been produced by the time the rock pressure reaches 1030 lb; consequently, the total amount of oil originally present is 2,000,000 divided by 0.04, which is 50,000,000 bbl. If by the time the pressure has fallen to 440 lb. (30 atm.) the total production is 5,500,000 bbl., these data can serve for another calculation of original amount of oil, which in this case is 46,000,000 bbl. By averaging a number of such calculations made from data taken at various periods in the life of the field, a fairly reliable estimate can be made.

The lack of essential data is the principal obstacle in applying the derived equation in this paper to most of the existing fields. The initial rock pressures were not recorded, the volumes of gas wasted during flush production were not measured, and the relative volumes of free gas and liquid in the reservoir at the start were not determined. The present trend is toward measuring and recording all pertinent data from the beginning. The usefulness of this equation emphasizes the need of gathering these data.

DISCUSSION

C. E. Beecher,* Bartlesville, Okla.—In the second curve, where you show no gas originally in the reservoir except that dissolved in the oil, do you return the gas to the sand?

H. D. Wilde, Jr.—Yes, all the gas produced with the oil is returned to the sand. The only difference is that in one case there is nine times as much liquid as free gas originally in the reservoir. If a very small portion of the gas that is produced is wasted, instead of being zero, g will have a value greater than zero and a different curve will result.

One of the practical difficulties in using these equations is the measurement of the ratio of gas-filled space to oil-filled space in the reservoir. However, a considerable error can be made in estimating the value of m without seriously affecting the curve. With a knowledge of the geological conditions and observation of the gas-oil ratio of new wells, one can estimate how much free gas was in the pool originally. The error there may be as high as 25 per cent., but this is not serious for even if considerable error in estimating m is made, the curve will be close to what it should be, and if m were given too low, the curve would be lower, which would be to your benefit, as it would show that pressure is maintained longer than you calculated.

C. J. Deegan,† Ponca City, Okla.—I understand that your calculations on the amount of recoverable oil are based on the assumption that 240 cu. ft. is the maximum amount that can be in solution?

H. D. Wilde, Jr.—No, we have merely assumed a case where the solubility is 240 cu. ft. per barrel. We know of fields in which the solubility is 240 cu. ft. under approximately 1500 lb. In others it may be more or less. The solubility should be determined for any particular field for which calculations are to be made.

C. J. Deegan.—Was it mixed gas?

H. D. Wilde, Jr.—Yes, 88 per cent. methane, the remainder ethane and propane.

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Condensation Effect in Determining Gas-oil Ratio

By Alexander B. Morris,* Tulsa, Okla.

(Tulsa Meeting, October, 1929)

In a recent paper on the intermittent injection of gas in gas-lift operations as opposed to continuous injection, Morgan Walker presented a comparative table showing the effect on oil and gas production from the same wells under the two methods of operation.[1] This table carried a column showing the formational gas-oil ratios under each method, computed by deducting the volume of input gas from the volume of trap gas.

During the entire spring and summer of 1928, the present writer had been engaged on some extensive test car tests of rich gas in Glenpool, seeking, primarily, for an explanation of the apparent loss of gasoline during the summer season between the field meters and the plant master meter. Tests at several of the field meters where the richest gas was obtained regularly failed to check with other tests on the same gas made farther along the line, and the difference was not made up by the quantity of drip gasoline collected between the points. In the course of these tests, the final outcome of which is immaterial to the present purpose, an attempt was made to construct a curve representing the relationship between gasoline content of the gas in gallons per thousand cubic feet and the shrinkage in the volume of gas treated as a result of removing the condensible fractions. Such a curve was made, expressed in units of gallons per thousand cubic feet on the abcissa and the ratio vapor volume to liquid volume on the ordinate. This curve is a rectangular hyperbola and shows that 3 gal. of gasoline taken from 1000 cu. ft. of raw gas as a vapor occupied much less space, per gallon, than did 1 gal. of gasoline taken from 1000 cu. ft. of another sample of gas. This is, in general, corroborated by converting to the same units the residue settlement curves prepared by the Tidal Oil Co. and by the Natural Gasoline Manufacturers Assn., though the three curves, when plotted together, occupy entirely different positions on the paper, as shown in Fig. 1.

The bearing of all this on Mr. Walker's discussion of gas-lift is this: if the formational gas is to be computed by deducting the input gas from the trap gas, some correction must be made for the vapor volume

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[1] M. Walker: Intermittent Injection of Gas in Gas-lift Installations. Petroleum Development and Technology, A. I. M. E. (1928–29) 158.

of the gasoline picked up by the dry input gas on its traverse of the system. This may seem at first to be almost negligible, but a little figuring from the production data given by Mr. Walker, using one of these volumetric ratio curves, will show that the corrections are by no means negligible, and that they may even be so great as to indicate an actual repressuring of the well, where, by ordinary methods of computation formational gas was taken from it. In other words, it is possible

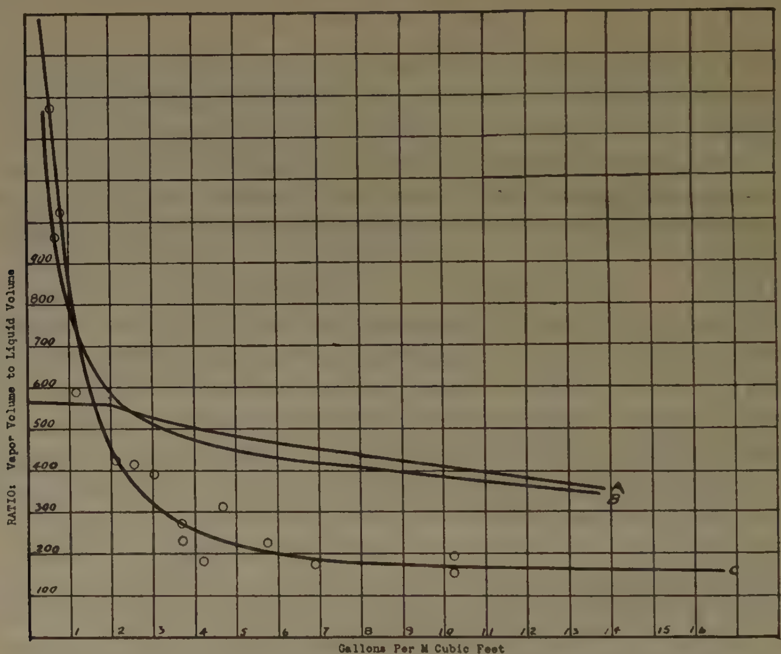

Fig. 1.—Gasoline condensation ratio.

Vapor volume to liquid volume showing substantial agreement in type of results. *A*, from Natural Gasoline Assn.; *B*, from Tidal Oil Co.; *C*, from truck tests by author.

that in many instances the vapor volume of the gasoline carried from the well in the trap gas is greater than the difference between the volume of trap gas and the volume of input gas.

Gasoline Content of Trap Gas

Unfortunately, the writer has had little opportunity to pursue these investigations in the field and to carry on prolonged observations of the wells under varying conditions, hence the present discussion is necessarily along academic lines. It was desirable, however, even for this approach, to determine a proper starting point or standard of comparison for the gasoline content of the trap gas. Charcoal tests were

made at two wells of the Amerada Petroleum Corpn. in the Seminole area. Trap pressures were varied and tests made at each of several

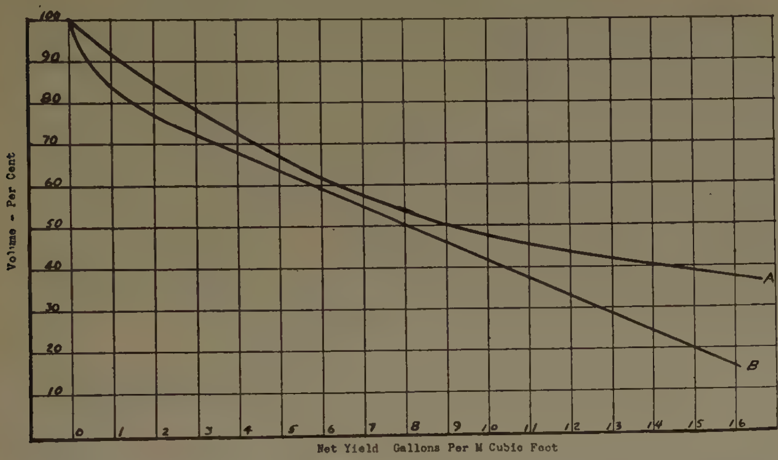

FIG. 2.—EFFECT OF TRAP PRESSURE ON GASOLINE CONTENT OF TRAP GAS. *A*, Hallum No. 4; *B*, Anderson No. 2. Charcoal test made July 7 and 8, 1929.

different pressures with surprisingly regular results. These are shown in Fig. 2. As the trap pressure is raised, the gasoline content of the trap gas falls. The parallelism between these curves for these two wells seems to indicate that the gas from each well constitutes a special set of conditions giving rise to a continuous curve for that particular gas. Probably analyses of these gases, sampled at the different pressures, would disclose the key to this behavior, but no such analyses were made. It is therefore necessary to neglect trap pressures altogether in this discussion, but to bear in mind that variations in trap pressure will vary the gasoline content of the trap gas. Let us assume, therefore, that trap pressures are constant under the two methods of production, and proceed to an analysis of some of the data submitted in Mr. Walker's paper. As he did not furnish any figures for the gasoline content of the trap gases corresponding to the other information, it will be necessary also to assume these as well. The values chosen for these contents are as follows: Continuous flow, 1.5 gal. per 1000 cu. ft.; intermittent flow, 2.5

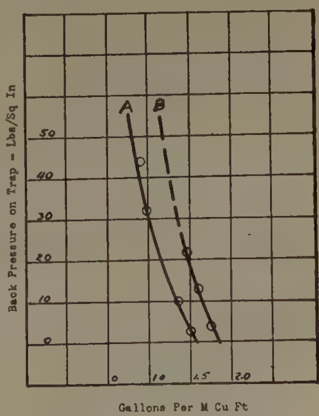

FIG. 3.—GAS CONVERSION CURVES.

Showing percentage of original volume remaining after extraction of gasoline. *A*, Natural Gasoline Assn.; *B*, Tidal Oil Co.

gal. per 1000 cu. ft. Referring to conversion curve B, Fig. 3, as being as good a standard as any readily available, it will be seen that the removal of 1.5 gal. of gasoline from gas having that total content leaves 80 per cent. residue; 2.5 gal. gas leaves 75 per cent. residue. In the following calculation, lines A, B, C and E are taken directly from Mr. Walker's data, or in practice, would be supplied by observation.

Line $D = C - B$
Line $E = D \div A$
Line F is the assumed gasoline content of trap gas. (In practice, actual values should be determined.)
Line G is the corresponding factor from a conversion curve.
Line $H = G \times C$
Line $J = H - B$
Line $K = C - H$
Line $L = K \times (J \div H)$
Line $M = K \times (B \div H)$
Line $N = B + M$
Line $P = J + L$
Line $R = N + P = C$
Line $S = P \div A$ = Actual gas-oil ratio

TABLE 1.—*Type of Computation Used to Arrive at Corrected Gas-oil Ratio*

LINE	ANDERSON NO. 2	CONTINUOUS FLOW		INTERMITTENT FLOW
A	Barrels oil	1077		1123
B	Input gas, dry, 1000 cu. ft.	1516		906
C	Trap gas, wet, 1000 cu. ft.	1762		1775
D	Apparent formational gas	246	$(C - B)$	869
E	Apparent formational gas-oil ratio	228	$(D \div A)$	773
F	Assumed gasoline content of trap gas. From curve B, Fig. 3,	1.5		2.5
G	Residue in per cent. of total	80		75
H	Dry gas returned to trap	1410	$(G \times C)$	1331
J	Dry formational gas	−106	$(H - B)$	425
K	Gasoline vapor recovered	352	$(C - H)$	444
L	Gasoline vapor carried by new gas	$352 \times \frac{-106}{1410} = -26$		$444 \times \frac{425}{1331} = 141$
M	Gasoline vapor carried by input gas	$352 \times \frac{1516}{1410} = 378$		$444 \times \frac{906}{1331} = 303$

Vapor conditions at emergence from trap:

		Continuous: Dry Gas plus Gasoline Vapor = Wet Gas	Intermittent: Dry Gas plus Gasoline Vapor = Wet Gas
N	Input gas	1516 + 378 = 1894	906 + 303 = 1209
P	Formational gas	− 106 − 26 = − 132	425 + 141 = 566
R	Total trap gas	1410 + 352 = 1762	1331 + 444 = 1775
S	Gas-oil ratio corrected for condensate	$-\frac{132}{1077} = -\ 122.5$	$\frac{566}{1123} = 505$

The figures given in Table 2 are taken from Table 1 of Mr. Walker's paper, and two columns are added, giving the gas-oil ratios computed when condensation effect is considered. The extent of some of these changes is really surprising. For example, Killingsworth 3, under continuous flow, by the ordinary calculation of merely subtracting the input

TABLE 2.—*Comparison of Gas-oil Ratios*

Computed by Ordinary Method and by Method Suggested. Basic Figures Taken from Table 1 in Mr. Walker's Paper

	Oil, Bbl. per Day		Inlet Gas Volume, 1000 Cu. Ft. per Day		Trap Gas Volume, 1000 Cu. Ft. per Day		Formational Gas-oil Ratio, Cu. Ft. Gas per Bbl. Oil			
							Apparent		Actual	
	Continuous	Intermittent	Continuous	Intermittent	Continuous	Intermittent	Continuous	Intermittent	Continuous	Intermittent
Anderson No. 2	1077	1123	1516	906	1762	1775	228	773	−132	505
Cowden No. 4	1087	1124	1525	1070	1750	1760	207	613	−144	297
Nitey No. 3	986	1024	1301	897	1365	1135	65	232	−673	− 54
Nitey No. 2	914	900	904	767	1171	1021	292	282	45	− 3
Nitey No. 4	873	....	1046	....	1281	....	269	....	− 30	......
Fixico No. 3	400	475	1380	864	1410	1652	75	1660	−787	1052
Rentie No. 3	508	517	1014	937	1275	1332	514	745	15	14
Killingsworth No. 3	326	290	966	860	1082	1130	367	932	−384	− 55
Cowden No. 3	279	285	1111	578	1220	1200	391	2180	−602	1505

Minus signs in actual gas-oil ratio column indicate actual repressuring of sand, where, by ordinary method of calculating gas-oil ratio, formational gas is being removed from sand.

gas from the trap gas, shows that 367 cu. ft. of gas is being removed from the sand for every barrel of oil taken out. By the method of calculation suggested herein, 384 cu. ft. of gas is actually being returned to the sand for every barrel of oil withdrawn.

It is admitted that many of the factors used in these calculations are open to serious question. No two conversion curves made independently and by different methods can be made to check within 25 per cent. or more. The actual observed gasoline content of the trap gases has had to be assumed. The results therefore are without quantitative value as applied to the particular wells from which the basic data were obtained. The point of the whole matter is: If gas-oil ratios are to be used as a guide to recovery efficiency, production methods, and forecasts as to the life of a field, they should be computed with due regard to all the factors involved, of which condensation effect is an extremely important one. Any carefully prepared conversion curve is better than none. Actual gasoline content is easily determined. Careful measurements of trap gas under different pressures, and almost continuous testing for gasoline content, would be necessary to determine the effect of trap pressures on total gasoline output. If these elements are given weight, however inaccurate they may be in themselves, the results obtained through their use will be a much more valuable guide than any result that ignores all of them and the fundamental principles which they represent.

DISCUSSION

S. F. Shaw,* Tulsa, Okla. (written discussion).—The paper presented by Mr. Morris is especially timely, since studies of gas-oil ratios have become of much importance in connection with the new methods of producing oil. Comparisons of gas-oil ratios cannot be made with any degree of satisfaction or accuracy unless some standard method is adopted for determining the degree of separation of gas from the oil. Oil that is produced under back-pressures contains gas in varying degree of liquefaction, solution and entrainment. This gas should be taken into account.

In a paper presented by C. C. Taylor,[2] the figures given in Table 3 are presented regarding quantities of gas left in the oil from the Santa Fe Springs field, under given back-pressures.

Table 3.—*Gas Left in Oil under Back-pressure*

Oil, Bbl. per 24 Hr.	Total Gas-oil Ratio, Cu. Ft. per Bbl.	Primary Trap Data			Secondary Trap Data		
		Temperature, Deg. F.	Pressure, Lb. per Sq. In.	Gas-oil Ratio, Cu. Ft. per Bbl.	Temperature, Deg. F.	Pressure, Lb. per Sq. In.	Dissolved and Entrained Gas in Oil, Cu. Ft. per Bbl.
5155	2819	128	300	2576	96	16	243
4067	1256	132	300	869	109	16	387
4175	1518	131	300	1241	112	8	277
5826	4430	123	300	4090	104	14	340
2622	3775	125	200	3640	95	7	135
3326	3165	122	200	2990	92	8	175

These figures show that when the oil and gas are under back-pressures and when separated in the primary trap considerable quantities of gas pass through with the oil to the secondary separator, and that the higher back-pressures allow greater quantities of gas to be carried along with the oil than do the lower back-pressures. In the second case cited in the table, the gas carried with the oil amounted to an increase of 44 per cent. of that measured in the first trap. Unless samples of the oil were taken from the secondary trap, and the gas separated and measured, there would be an additional quantity to be taken into account, since there remained a certain back-pressure on the secondary trap. These figures for Santa Fe Springs operations indicate the divergent results for gas-oil ratios that can be obtained unless the gas is measured under standard conditions.

Apparently inconsistent results for gas-oil ratios have been noted in the Seminole field, where tests are being made on gas-lift wells at frequent intervals, with discharge from the trap being made usually at close to atmospheric pressure. The example in Table 4 will indicate the amount of variation in a well where production remained constant but where variable quantities of input gas were admitted.

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* Consulting Engineer, Carter Oil Co.

[2] C. C. Taylor: Modern Gas Trap Installation. California Natural Gasoline Assn. (February, 1929).

TABLE 4.—*Effect of Varying Input Gas*

Oil per Day, Bbl.	Back-pressure on Trap	Gas per Minute, Total Cu. Ft.		Gas per Barrel of Oil, Cu. Ft.		
		Input	Output	Input	Output	Gas-oil Ratio
826	0	830	1273	1445	2217	772
826	0	1055	1539	1837	2680	843
826	0	1286	1819	2240	3169	927

The apparent difference in the gas-oil ratio, from 772 cu. ft. to 927 cu. ft. per bbl., is not due to back-pressure or to temperature, but to the degree of gasification of the oil. In other words, the oil was brought into more intimate contact with the gas by using a larger quantity of gas and obtaining a greater degree of spray or mist. As the quantity of gas was increased better contact was obtained, and thereby a greater degree of separation of the gas from the oil was also obtained. There was an apparent increase of 20 per cent. in the gas-oil ratio even under constant conditions of pressure and temperature; what, then must be the variation in gas-oil ratios that can be obtained where all the factors enter, such as back-pressure, temperature, and degree of gasification?

At Seminole, we find oil that is pumped of 41° gravity, while the oil produced from the same well by gas-lift is sometimes as low as 36° gravity. This change is caused by the removal of a greater quantity of gas from the oil by the gas-lift, and sometimes, if we compare the results directly, we seem to have a greater gas-oil ratio when employing the gas-lift than when the well is being pumped. This difference is only apparent, however, since we can advance no sound reason for a greater gas-oil ratio with one method than with the other, if the quantity of oil lifted remains constant.

I. GARDESCU,* Pittsburgh, Pa.—The gas-oil ratio is not always in a condition of equilibrium corresponding to a saturated solution. More gas can be present in solution than shown by experimental data, generally accepted. This is especially true when the pressure of the oil is gradually reduced, in which case there is a pronounced lag in the rate of escape of gas, resulting in a supersaturated solution. Turbulent flow and vigorous shaking tend to establish a normal saturated condition. In measuring the gas-oil ratio, I believe that it is necessary to ascertain the degree of saturation, which in some cases might be different from the values obtained assuming a normal saturated solution.

* Petroleum Engineer, Research Department, Gulf Production Co.

Chapter IV. Hydraulics in Flowing Wells

Mathematical Development of the Theory of Flowing Oil Wells

By J. Versluys,* The Hague, Netherlands

(Tulsa Meeting, October, 1929)

When a well strikes an oil-bearing layer, the oil has a pressure which is generally sufficient to enable it to rise to near the surface (sometimes above the surface). As soon as a well begins to produce, however, the liquid moves through the pores of the reservoir bed and the pressure in the well becomes much lower than the pressure originally prevailing there. At some distance from the well, however, the pressure in the reservoir bed remains unaltered; thus the pressure of the oil has not only to lift the oil, but also to overcome the friction resistance in the pores. The fact that so many oil wells are gushers is a consequence of the energy accumulated in the gas.

In gushing the well acts as a gas-lift. A mixture of liquid and gas (the latter partly dissolved in the former) rises vertically from the oil-bearing layer through a cylindrical casing to the surface. In time conditions alter and the well ceases to gush regularly, then the gushing can be further promoted by inserting a narrower tube in the well and connecting the top of the oil string to the tubing. If the action in time becomes irregular, the gushing can be kept up for a further period by forcing gas between the two tubes. In the oil fields the term "gas-lift" is used actually only where extraneous gas is applied, as in the last of the stages mentioned. The action, however, is just the same whether the gas exclusively originates from the formation, or is partly applied artificially. Thus by gas-lift we simply mean a vertical tube in which the energy of gas under pressure, and of dissolved gas, is utilized for raising a liquid.

In gushing oil wells the pressure is frequently very high and the absorption coefficient 0.4 (expressed in vol. ratio) of the coexisting gas is not particularly high, so that in reality it should be assumed that a considerable portion of the gas, at any rate at the bottom of the gas-lift, is dissolved in the oil. For water-producing wells this is not usually of such importance.

Where the volume of the flowing gas is much greater than that of the flowing liquid, the latter can be suspended in the former in the form of

* Adviser to the Bataafsche Petroleum Maatschappij.

minute drops. Where, however, the gas ratio is smaller, it is possible to speak of gas bubbles in the liquid. Some authors say that there are alternating slugs of liquid and gas in the tubing.

Two cases will be separately treated in this paper: (1) where the gas is insoluble in the liquid to be lifted and (2) which is more complicated than the first, where the gas is soluble in the liquid.

Function of Pressure

The pressure at the bottom of the gas-lift is greater than at the top. The pressure difference, however, is too small to lift the liquid; *i. e.*, the pressure at the bottom is smaller than the pressure at the top combined with the pressure of a liquid column, the height of which is equal to the length of the gas-lift. If the gas-lift (tube) were entirely filled with liquid, it would act in reverse direction; a downward movement would then in fact take place. The tube, however, is filled with a mixture of gas and liquid, which is here presumed to be very closely intermingled; *i. e.*, the one substance is very finely distributed in the other. The specific gravity of the mixed column of the two substances is lower than that of the liquid; consequently the pressure difference at the two ends of the gas-lift can cause a rising movement. This pressure difference, if the column is once filled with a mixture of gas and liquid, may be primarily considered as the cause of the movement, but it will be found later on that the pressure at the bottom of the column filling the lifting tube performs a positive work, which is not much greater than the negative work of the pressure at the surface. There must thus be a source of energy and this source is the expansion of the gas in the lifting tube. An explanation as to the manner in which the work performed by the expanding gas is able to raise the weight of the liquid and that of the gas is by no means simple and will not be attempted here. It will be assumed, however, that the expansion work carried out by the gas while moving from the bottom of the gas-lift to the top (whereby the pressure declines) is the principal source of work that causes the rise.

During the rise the gas volume increases, so that the velocity of the mixture increases with the height in the lifting tube. Work will thus have to be performed to increase the kinetic energy of gas and liquid. The weight of the gas and the liquid will rise so that the gravity will perform negative work and thus the same amount of positive work will have to be supplied by the available sources of energy. Further, a resistance will be set up in the tube which we shall term here the "turbulence resistance." This resistance will perform negative work.

One can compute that if all gas (see No. 20 in the bibliography at the end) accompanying the oil were free, the drop of temperature would be 1° C. in approximately 700 ft., depending principally on the specific heat of the oil. In case a part of the gas is dissolved in the oil, this is set free

as the oil rises and the pressure declines. This would cause a greater drop of temperature. The consequence of a drop of temperature is a loss of energy, the gas no longer expanding isothermally. We can compute, however, that the loss of energy practically never will amount to more than 0.5 per cent. of the total energy exerted during the expansion of the gas in the tube. So we will presume that we remain within the limits of inaccuracies if we neglect differences of temperature.

Positive work is performed by the pressure on the bottom of the column and negative work by that on the top.

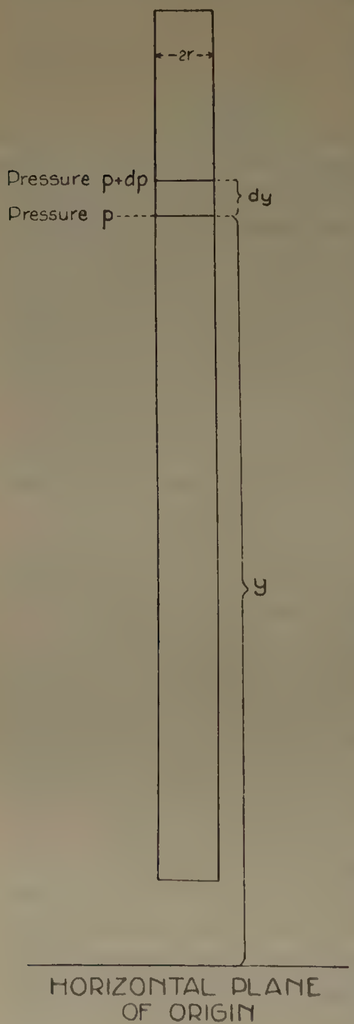

FIG. 1.

WORK EQUILIBRIUM

All this work in each unit of time must equilibrate the work performed by the expansion of the gas. It is for the moment assumed that liquid and gas move at the same speed. On this assumption an equation will be composed expressing the equilibrium of the work performed in a unit of time, in the various ways described, in an elementary cylinder; *i. e.*, in a section of the gas-lift tube lying between two planes at the levels y and $y + dy$ above a certain level of origin (see Fig. 1). The following nomenclature will be assumed:

Height above a certain horizontal plane of origin . . . . y
Volume of liquid passing per unit of time . . . . q
Volume occupied at atmospheric pressure by quantity of gas passing per unit of time . . . . nq
Specific gravity of liquid . . . . γ_l
Specific gravity of gas at atmospheric pressure . . . . γ_g
Pressure at level y above level of origin in atmospheres . . . . p
Pressure in chosen units of force per unit of area . . . . ap
Radius of cross-section of tubing . . . . r
Velocity of upward movement . . . . w
Combined volume of oil and gas flowing through cross-section per unit of time v

Combined weight of gas and oil flowing through cross-section per unit of time . . . . G

Same for liquid alone . . . . G_l

Same for gas alone . . . . G_g

Specific gravity of mixture . . . . s

Hence at a level y the weight of $1 + \frac{n}{p}$ volume units of the mixture is $\gamma_l + n\gamma_g$ and the specific gravity of the mixture at the level y:

$$s = \frac{\gamma_l + n\gamma_g}{1 + \frac{n}{p}} = (\gamma_l + n\gamma_g)\frac{p}{p + n}. \qquad [1]$$

The volume of the mixture flowing per unit of time through the cross-section at level y is: liquid, q; gas, $\frac{n}{p}q$; and combined, $v = \frac{p+n}{p}q$ [2]

The weight of the quantity of mixture flowing per time unit through the cross-section is composed of the weight of the liquid $q\gamma_l$ and of the gas $nq\gamma_g$

$$G = q(\gamma_l + n\gamma_g). \qquad [3]$$

The speed with which this mixture rises at level y is:

$$u = \frac{v}{\pi r^2} = \frac{q}{\pi r^2}\frac{p+n}{p}. \qquad [4]$$

The pressure exerted on the bottom surface of the elementary cylinder is in grams per square centimeter pa and that on the top surface is $(p + dp)a$.

Through the former surface a volume of liquid $\frac{p+n}{p}q$ enters the elementary cylinder per unit of time and the pressure on this surface thus performs per unit of time a work of $aq(p + n)$. In the same way the pressure on the top surface performs a work of $-aq(p + dp + n)$, so that the total work performed by the pressure is

$$dW_1 = -aqdp. \qquad [5]$$

It should not be lost sight of that in the gas-lift the pressure decreases as y increases, so that dp has a negative value. The quantity of work expressed by equation 5 is therefore positive.

A weight of oil and gas G (see formula 3) enters through the bottom surface per unit of time and an equal quantity of substance passes out of the elementary cylinder through the top surface. Hence the work of gravity is per unit of time:

$$dW_2 = -Gdy = -q(\gamma_l + n\gamma_g)dy. \qquad [6]$$

The negative sign is inserted here because the force of gravity is directed downwards. The substance entering through the bottom sur-

face per unit of time has a mass of $\frac{G}{g}$ and a speed of u, so that per unit of time it supplies a kinetic energy of:

$$\frac{1}{2}\frac{G}{g}u^2 \tag{7}$$

to the elementary cylinder.

In the same way a kinetic energy of:

$$\frac{1}{2}\frac{G}{g}(u + du)^2 \tag{8}$$

is lost in the speed of the out-flowing substance and thus acceleration supplies per unit of time an amount of work equaling:

$$dW_3 = -\frac{1}{2}\frac{G}{g}\frac{du^2}{dp}dp = \frac{q^3n}{\pi^2r^4g}(\gamma_l + n\gamma_g)\frac{p + n}{p^3}dp. \tag{9}$$

Further work in the elementary cylinder is lost by the turbulence resistance. The loss of pressure per unit of length on account of this resistance will be discussed later on; it is expressed by the formula in which the specific gravity s, and also the speed, are included. Both are dependent on the pressure p so that for the drop of pressure per length unit at a pressure p the following can be taken:

$$\frac{dp}{dy} = f(p). \tag{10}$$

The work performed by this pressure loss in an elementary cylinder per time unit is the product of the drop of pressure, the volume flowing through and the length of the elementary cylinder.

So if f is written as abbreviation for formula 10, one can generally take:

$$dW_4 = -\pi r^2 fudy = -q\frac{p + n}{p}fdy. \tag{11}$$

The gas at the bottom surface of the elementary cylinder has a pressure p and at the top surface $p + dp$; so the volume at the bottom surface is $\frac{nq}{p}$ and at the top surface $\frac{nq}{p + dp} = \frac{nq}{p} + d\frac{nq}{p}$. The volume of gas passing through the elementary cylinder per unit of time therefore increases by $d\frac{nq}{p} = -\frac{nq}{p^2}dp$. Hence the work performed by the pressure of the gas owing to this expansion is:

$$dW_5 = -anq\frac{dp}{p} \tag{12}$$

and this amount of work is supplied to the elementary cylinder.

If there is no other energy loss than that of the turbulence dW_4, one can write:

$$dW_1 + dW_2 + dW_3 + dW_4 + dW_5 = 0 \tag{13}$$

or (see formulas 5, 6, 9, 11, 12):

$$-qadp - q(\gamma_l + n\gamma_g)dy + \frac{q^3n}{\pi^2r^4g}(\gamma_l + n\gamma_g)\frac{p+n}{p^3}dp - q\frac{p+n}{p}fdy - anq\frac{dp}{p} = 0, \quad [14]$$

in which all terms can be divided by q and in which the terms including dy and those including dp can be separated from each other.

$$\left\{(\gamma_l + n\gamma_g) + \frac{p+n}{p}f\right\}dy = \left\{-\frac{an}{p} - a + \frac{q^2n}{\pi^2r^4g}(\gamma_l + n\gamma_g)\frac{p+n}{p^3}\right\}dp. \quad [15]$$

The value of f is (see No. 16 in bibliography) dependent on p, but y does not occur in it, so that the variables can be separated, and a further simplification can be made as follows:

$$dy = \frac{-a\frac{p+n}{p} + \frac{q^2n}{\pi^2r^4g}(\gamma_l + n\gamma_g)\frac{p+n}{p^3}}{(\gamma_l + n\gamma_g) + \frac{p+n}{p}f}dp. \quad [16]$$

This equation can be solved if a certain function is substituted for f. For this purpose the following is taken:

$$f = \frac{\varphi v^2 s}{r^5} = \frac{\varphi q^2}{r^5}\left(\frac{p+n}{p}\right)^2(\gamma_l + n\gamma_g)\frac{p}{p+n} \quad [17]$$
$$= \frac{\varphi q^2}{r^5}(\gamma_l + n\gamma_g)\frac{p+n}{p},$$

in which φ is a constant, converting formula 16 into:

$$dy = \frac{-a\frac{p+n}{p} + \frac{q^2n}{\pi^2r^4g}(\gamma_l + n\gamma_g)\frac{p+n}{p^3}}{(\gamma_l + n\gamma_g)\left\{1 + \frac{\varphi q^2}{r^5}\left(\frac{p+n}{p}\right)^2\right\}}dp. \quad [18]$$

By taking formula 17 as applicable, it is assumed that in so far as concerns the turbulence, the mixture of gas and liquid behaves as a single liquid or as a single gas, while the effect of the viscosity is disregarded. This assumption is probably not entirely correct (see No. 16 bibliography) but there are further inaccuracies or incompletions, the deduction of which will be facilitated by the introduction of coefficients, the dependence of which of the pressure p will have to be ascertained by experiment. So in formulas 17 and 18, φ is probably a function of p; there is, however, a means of ascertaining this by experiment.

Another incompletion is this. The speed in the various points of a cross-section is not the same and consequently dW_3 expressed by formula 9 is too small. In formula 9 a further coefficient ψ will therefore have to be inserted, which will again depend on p. Presumably φ and ψ are both dependent on q, r and n, which can likewise be ascertained by experiment.

If the coefficient ψ is inserted in formula 18, this equation can be converted to:

$$(\gamma_l + n\gamma_g)\left\{1 + \frac{\varphi q^2}{r^5}\left(\frac{p+n}{p}\right)^2\right\} + a\frac{p+n}{p}\frac{dp}{dy} - \frac{\psi q^2 n}{\pi^2 r^4 g}(\gamma_l + n\gamma_g)\frac{p+n}{p^3}\frac{dp}{dy} = 0 \quad [19]$$

If a mixture of gas and liquid is allowed to rise through a vertical tube of a certain diameter and one knows the pressure at levels which are not very far apart, a value for $\frac{dp}{dy}$ in formula 19 will be found.

For this purpose we take: $\frac{dp}{dy} = \frac{p_2 - p_1}{y_2 - y_1}$, [20]

if p_2 and p_1 are respectively measured at the levels y_2 and y_1.

Tests can now be carried out with different values of γ_l, γ_g, q, n, r, p, and $\frac{dp}{dy}$. Then formula 19 will always give an equation including two unknown factors φ and ψ. It is possible to make a series of tests whereby only one of the magnitudes mentioned to be deduced from tests is altered, and thus the dependency of φ and ψ on all these magnitudes can be successfully ascertained.

Till now it has been assumed that gas and liquid rise with the same speed, but that is incorrect. Whatever the condition may be, whether the gas is distributed in the liquid in the form of bubbles, or the liquid in the shape of drops in the gas, the gas will have the greater velocity. Gas bubbles which rise in a liquid attain a certain maximum speed and such is also the case with liquid drops sinking in a gas.

If drops with a combined weight of M, with a uniform speed b, sink in a space filled with gas, gravity performs per unit of time a work of:

$$Mb \quad [21]$$

and as the kinetic energy of the liquid does not increase, the gas resistance performs an equally important work with the opposite sign. If the speed difference is b, a quantity of energy is thus lost in the elementary cylinder per unit of time, equaling the product of this speed difference and the weight of the liquid in the cylinder. If the gas has a velocity of u_2 and the liquid u_1, then:

$$u_2 - u_1 = b \quad [22]$$

The ratio of the volumes of liquid and gas in each section is as $q:\frac{nq}{p}$ if they have the same velocity. The ratio, however, becomes as $\frac{1}{u_1}:\frac{n}{pu_2}$ or as $\frac{1}{u_2 - b}:\frac{n}{pu_2}$. So the volume of the liquid in an elementary cylinder is:

$$\pi r^2 \frac{pu_2}{pu_2 + nu_2 - nb} dy. \tag{23}$$

Hence the energy supplied to the elementary cylinder by the velocity per unit of time is:

$$dW_6 = -b\gamma_l \pi r^2 \frac{pu_2}{pu_2 + nu_2 - nb} dy. \tag{24}$$

The velocity b now becomes one of the magnitudes of which the value is to be determined empirically. If it is borne in mind that this depends on the other magnitudes, including the variable p, the following can be approximately taken:

$$dW_6 = -b\gamma_l \pi r^2 \frac{p}{p + n} dy. \tag{25}$$

Consequently a term dW_6 has to be added to formulas 13 and 14. It should not be forgotten, however, that the kinetic energy alters and consequently also formula 9 again, so that the coefficient ψ undergoes a further alteration. The same presumably applies for φ.

The work dW_1 does not alter according to the deduction of formula 5; neither do dW_2 and dW_5 alter according to the deductions of formulas 6 and 12.

Instead of No. 19 the following formula can be obtained by adopting the new term:

$$q(\gamma_l + n\gamma_g)\left\{1 + \frac{\varphi q^2}{r^5}\left(\frac{p+n}{p}\right)^2\right\} + aq\frac{p+n}{p}\frac{dp}{dy} - \frac{\psi q^3 n}{\pi^2 r^4 g}(\gamma_l + n\gamma_g)\frac{p+n}{p^3}\frac{dp}{dy} + b\gamma_l \pi r^2 \frac{p}{p+n} = 0 \tag{26}$$

From this, after substitution of the values of the other magnitudes determined by experiments, φ, ψ and b have to be solved and these will probably prove to be dependent on the other magnitudes. As φ, ψ and b are functions of y, not directly involving p, the variables in formula 26 can be separated, but the solution of this differential equation would be so complicated that it could not be applied in practice, unless it could be simplified by some justifiable omission. Should this not be the case, then for the application of the formula the gas-lift must be supposed to be divided into sections where the pressure respectively alters from p_1 to p_2, from p_2 to p_3, etc., and in which the average pressures $\frac{p_1 - p_2}{2}$, $\frac{p_2 - p_3}{2}$, etc., have to be assumed. If l_1, l_2, etc., are the lengths over which the

pressure decreases from p_1 to p_2, from p_2 to p_3, etc., then in formula 26 one may assume respectively:

$$\frac{dp}{dy} = \frac{p_1 - p_2}{l_1}, \; \frac{dp}{dy} = \frac{p_2 - p_3}{l_2}, \text{ etc.} \qquad [27]$$

Finally, formula 26 also provides the means of determining the most suitable value of r; that is, the solution whereby $\frac{dp}{dy}$ has the minimum value. Therefore the formula enables us to calculate what diameter the lifting tube should have at each level in order to obtain the most advantageous effect.

In case the volume of the gas is much greater than the volume of the liquid, we may take it as an approximation that M is the weight of the oil and b the difference of speed in formula 21. But if the volume of the liquid prevails, for M we could substitute the weight of a volume of oil equal to that of the gas contained in the elementary cylinder, and for b again we should substitute the difference of speed. Also we could substitute for M again the weight of the liquid in the cylinder and for b a velocity smaller than the difference of speed above mentioned. In this case b would be approximately inversely proportional to p. Without having made any experiments, we may presume that if the diameter of the tube is so great that u would be equal to b, no lifting would take place, and this means that the action of the lift would be intermittent.

Efficiency of Gas-lift

It is not always possible to indicate the exact efficiency of the gas-lift. The gas that is led from the surface to the bottom of a well in order to rise in the gas-lift is compressed to a certain pressure, which is smaller than the pressure at the bottom of the gas-lift. The work performed for this compression is the work supplied. The effective work is that which would have been required for bringing up the liquid. While the gas is led to the bottom of the gas-lift through the space between the lifting tube and the oil string, gravity is performing work and thus in the gas-lift more work is performed by the expansion of the gas than the compressor supplies.

Where an oil well is concerned and the gas comes either wholly or partly from the oil-bearing layer, this gas is also brought up and the required work is considerable because the weight of the gas can be greater, exceptionally, than that of the oil. Is the work required for this effective work or not?

Work Equilibrium with Soluble Gas

If the gas is soluble the question becomes more complicated than in the case of an insoluble gas dealt with above; in fact, now the weight of

the gas and also that of the liquid is variable according to the pressure.

The velocity difference between liquid and gas will be taken into account from the beginning.

Absorption coefficient will be represented by α, pressure at which all available gas would be dissolved, by P.

The free gas flowing through a section per unit of time would, at a pressure of 1 atm., occupy a volume of:

$$\alpha q(P - p) \tag{28}$$

and at the prevailing pressure p, $\alpha q \dfrac{P - p}{p}$ [29]

hence
$$v = q + \alpha q \frac{P - p}{p} = \frac{p + \alpha P - \alpha p}{p} q \tag{30}$$

and
$$u = \frac{p + \alpha P - \alpha p}{\pi r^2 p} q. \tag{31}$$

Further
$$G_l = q\gamma_l + \alpha p q \gamma_g \tag{32}$$

and
$$G_g = \alpha(P - p) q \gamma_g \tag{33}$$

while
$$G = q\gamma_l + \alpha P q \gamma_g. \tag{34}$$

In these formulas, q, P, α, γ_l, γ_g, and r are unvariable while p is an independent variable.

Hence
$$dv = -\alpha q P \frac{dp}{p^2}. \tag{35}$$

and
$$du = -\frac{\alpha q P}{\pi r^2} \frac{dp}{p^2}. \tag{36}$$

Further
$$s = \frac{G}{v} = \frac{(\gamma_l + \alpha P \gamma_g) p}{p + \alpha P - \alpha p}. \tag{37}$$

This s represents the weight of liquid and gas per unit of volume. This can be split up as follows:

$$s = \frac{(\gamma_l + \alpha p \gamma_g) p}{p + \alpha P - \alpha p} + \frac{\alpha (P - p) p \gamma_g}{p + \alpha P - \alpha p}. \tag{38}$$

The last term in the formula refers to the free gas while the first refers to the oil with the gas dissolved therein. Thus with equal velocity of gas and liquid the weight of the liquid in an elementary cylinder is expressed by:

$$\pi r^2 \frac{\gamma_l p + \alpha p^2 \gamma_g}{p + \alpha P - \alpha p} dy. \tag{39}$$

If there is a velocity difference of b this weight is then:

$$\pi r^2 \frac{u}{u - b} \frac{\gamma_l p + \alpha p^2 \gamma_g}{p + \alpha P - \alpha p} dy. \tag{40}$$

The work performed by the pressure on the elementary cylinder per unit of time can be expressed as follows. The pressure at the bottom

surface is p and a volume v (see equation 30) enters through this surface per unit of time. So this pressure performs a work per time of unit of:

$$apv \tag{41}$$

In the same way the pressure on the top surface performs a work of:

$$-a(p + dp)(v + dv) = -a(pv + pdv + vdp) \tag{42}$$

Hence the total work of the pressure is:

$$dW_1 = -apdv - avdp = a\alpha qP\frac{dp}{p} - a\left(q + \alpha q\frac{P}{p} - \alpha q\right)dp = -aq(1 - \alpha)dp = -c_1dp \tag{43}$$

in which

$$c_1 = qa(1 - \alpha) \tag{44}$$

The work of gravity can be expressed as follows: a weight G (see equation 34) enters through the bottom surface per unit of time and through the top surface an equal quantity of substance flows out of the cylinder. So the work performed per unit of time is:

$$dW_2 = -Gdy = -q(\gamma_l + \alpha P\gamma_g)dy = -c_2dy \tag{45}$$

in which

$$c_2 = q(\gamma_l + \alpha P\gamma_g). \tag{46}$$

The kinetic energy which is communicated to the elementary cylinder is the difference between the kinetic energy of the substance flowing in per unit of time and that of the substance simultaneously flowing out. If all molecules in a cross-section actually had the velocity u respectively $u + du$, we could write:

$$dW_3 = \frac{1}{2}\frac{G}{g}\{u^2 - (u + du)^2\} = -\frac{G}{g}udu = \frac{q^3(\gamma_l + \alpha P\gamma_g)}{\pi^2r^4g}\frac{(p + \alpha P - \alpha p)\alpha P}{p^3}dp = f_3(p)dp \tag{47}$$

in which

$$f_3(p) = \frac{q^3(\gamma_l + \alpha P\gamma_g)}{\pi^2r^4g}\frac{(p + \alpha P - \alpha p)\alpha P}{p^3} \tag{48}$$

As in the case of an insoluble gas a coefficient ψ could again be adopted.

The resistance caused by the turbulence is dependent on the specific gravity of the mixture and on the velocity; so this is a function of the pressure p. For this resistance we shall provisionally take per unit of length:

$$f_4(p) \tag{49}$$

hence:

$$dW_4 = -f_4(p)dy \tag{50}$$

By the pressure of the gas, two kinds of work are performed, which, however, according to a previously deduced rule (see No. 19, bibliography), is equal to the work performed in case all the gas were free and expanded between the same pressure limits, in this case p and $p + dp$. So one can write:

$$dW_5 = ap\left(\frac{\alpha Pq}{p + dp} - \frac{\alpha Pq}{p}\right) = -a\alpha Pq\frac{dp}{p} = -f_5(p)dp, \tag{51}$$

in which

$$f_5(p) = \frac{a\alpha Pq}{p}. \tag{52}$$

Finally the negative quantity of work, which is performed per unit of time in consequence of the velocity difference, is expressed as the product of formula 40 and the velocity difference b with the negative sign. If in formula 40 the value of u expressed by formula 31 is substituted, we arrive at a complicated form. As b is usually small in comparison to u, it will not be a great error to assume:

$$\frac{u}{u - b} = 1. \tag{53}$$

Hence this quantity of work becomes:

$$\begin{aligned} dW_6 &= -\pi r^2 b \frac{\gamma_l p + \alpha p^2 \gamma_g}{p + \alpha P - \alpha p} dy \\ &= -b f_6(p) dy \end{aligned} \tag{54}$$

in which b is a coefficient which will presumably be found to be variable, and

$$f_6(p) = \pi r^2 \frac{\gamma_l p + \alpha p^2 \gamma_g}{p + \alpha P - \alpha p} \tag{55}$$

The equilibrium of the six quantities of work is expressed by:

$$-c_1 dp - c_2 dy + \psi f_3(p) dp - f_4(p) dy + f_5(p) dp - b f_6(p) dy = 0 \tag{56}$$

In the same manner as formula 17 was deduced, an approximate formula can now be found for

$$\begin{aligned} f_4(p) = \varphi \frac{v^2 s}{r^5} &= \frac{\varphi q^2}{r^5} \frac{(p + \alpha P - \alpha p)^2}{p} \frac{(\gamma_l + \alpha P \gamma_g) p}{p + \alpha P - \alpha p} \\ &= \frac{\varphi q^2}{r^5} \frac{p + \alpha P - \alpha p}{p}. \end{aligned} \tag{57}$$

The coefficients c_1 and c_2, and the functions $f_3(p)$, $f_4(p)$, $f_5(p)$ and $f_6(p)$ in the equilibrium equation can again be substituted by the form they assume in formulas 44, 46, 48, 57, 52 and 55. In this way an equation including the variables p, dp and dy is obtained, which is divided by dy and then converted into an equation including the variables p and $\frac{dp}{dy}$. For this equation the considerations given in respect to formula 26 again apply.

The surface tension probably influences the dispersion of gas and liquid, while the viscosity will not be entirely without effect on the action of the gas-lift. If the liquid is distributed in the gas, the viscosity of the gas would have an influence and that of the oil would influence only to a slight extent; in case the gas is dispersed in the oil, the viscosity of the oil will interfere. The viscosity and surface tension will presumably have some influence on the coefficients b, φ and ψ and b is not quite independent of the specific gravity of the gas and the absolute velocity of the oil, which depends on p. Numerous tests will have to be made to show whether this may be disregarded.

The foregoing considerations apply only in case the expansion of the gas and the liberation from the oil take place isothermally. That is not entirely the case. An unimportant part of the heat may be supplied from the surrounding materials, but nearly all the energy exerted by the expansion of the gas is equilibrated by the work expressed by dW_4 and dW_6 and thus converted into heat, so there is not much cooling in the gas-lift (see No. 20, bibliography). It often happens that solid substances are deposited from the oil in the gas-lift. This is not necessarily a consequence of cooling. It can also result partly from the evaporation of a portion of the lighter substances. The deposition of solid substances would give back heat to the liquid.

Conclusion

This paper gives the principles of a theory. The constants in the formulas must be ascertained from experiments, which should be performed on the basis of this theory.

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DISCUSSION

S. F. Shaw,* Tulsa, Okla. (written discussion).—Complete mathematical solution of the flow of mixed liquid and gas in gas-lift work is difficult to express, owing to the many conditions obtaining, and to the continually changing character of several variables in the same lifting operation. Many attempts have been made to express these variables in mathematical form, so far without success. Dr. Versluys' paper is an attempt to set forth such a mathematical formula, leaving the constants to be determined by trial. This is the logical manner in which to proceed, although there are difficulties to be encountered in this method of procedure for this particular operation.

Dr. Versluys correctly calls attention to the fact that the action of the gas-lift is the same whether the gas originates in the formation with the oil or is supplied from an external source. The gas supplied from outside the formation may differ in chemical formula from that found in the formation, and in that respect may set up different action, but this does not make for any difference in the lifting principles involved in gas-lift work.

Dr. Versluys calls attention to the fact that in natural flowing wells a considerable portion of the gas is dissolved in the oil at the bottom of the tubing; this is correct in many cases, though in many other cases it is not correct. In the Seminole field there are wells in the Cromwell sand making from 1000 to 10,000 cu. ft. of gas per barrel of oil. In one such well, on which several tests have been made, it was found that the gas-oil ratio was approximately 8000 cu. ft. per bbl. with bottom-hole pressure of about 500 lb. per sq. in., under which condition there can be scarcely 150 cu. ft. of gas contained in a barrel of oil; in other words, less than 2 per cent. of the gas issuing with the oil is dissolved in the oil. Similar conditions will be found in the old Cromwell pool, Oklahoma, in many of the southern California fields, in Rumania, and elsewhere. In fact, in the majority of wells flowing naturally, or flowing with the aid of air-gas lift, the amount of gas dissolved in the oil at the bottom of the tubing is a small percentage of the amount of gas issuing at the discharge. The following pressure at the bottom of the tubing is much lower than the rock pressure, consequently rock pressure should not be taken as a criterion of the flowing pressure; if the flowing pressure were not considerably lower than the rock pressure, there would be little flow of oil into the well.

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In the early days of air-lift work, diagrammatic explanations of the operation of the lift in many cases showed alternate slugs or pistons of liquid and gas in the tubing. This may have been the general theory of some authors, and experiments with glass tubing of small diameter will appear to bear out that theory, but capillary attraction in tubing of small diameter has a different effect from the action of the air-lift when employing tubing of large diameter. In a well flowing continuously in tubing of 1 in. dia. the flow does not take place in alternate slugs of liquid and gas, but is a flow in which the gas bubbles are constantly expanding and breaking, and are darting here and there through the liquid, as it rises in the tubing.

Dr. Versluys says that in gas-lift flow, a turbulence will be set up in the tubing which will perform negative work. This is true if we permit ourselves to use a collective term for the various kinds of resistance set up in the tubing, but in most cases this resistance to the flow is too great a percentage of the total work performed by the expanding gas to collect within one term, and the elements making up this resistance are not cumulative, nor do they directly offset each other, hence mathematical expression should be made of the various kinds of resistance before we can find a formula that can be successfully applied. So far, we recognize the following factors within the tubing that perform negative work:

1. Frictional resistance of the wall of the tubing, constantly changing.
2. Slippage of the liquid back through the gas.
3. Viscosity, varying throughout the length of the tubing.
4. Temperature of the fluid, constantly changing.
5. Other factors not yet recognized.

In applying a formula, there must be a differentiation between these factors because they are constantly changing throughout the length of the lift, and their combined effect is not cumulative. At the lower end of the tubing, in nearly all instances of practical application of the lift, the velocity is lower than in the upper part, consequently the friction along the surface of the pipe is less than at the discharge. On the other hand, owing to this lower velocity at the lower end, the slippage of the liquid back through the gas is greater than in the upper end where the velocity is higher. Throughout the entire movement there are also changes in viscosity and in temperature, and these changes have a pronounced effect on factors of friction and slippage. There is also another loss due to acceleration, which is not regarded by some authors as a loss; but since the primary object of the air-gas lift is to deliver liquid to a given point at the discharge, this alone should be considered as the quantity of useful work performed.

In many gas-lift operations, the mass of liquid is so great compared to that of the gas that there is little change of temperature, consequently very little error is involved if the lift be considered as acting under conditions of isothermal expansion. In instances where the volume of gas amounts to perhaps 10,000 or 20,000 cu. ft. of gas per barrel of oil, the temperature at the discharge is much lower than at the bottom of the tubing, and the action is not that of isothermal expansion. So far we do not know whether the change in temperature from the bottom to the discharge is uniform, therefore it is difficult to apply exponential formulas to this class of flow; for the present, the best we can do is to assume for purposes of calculation that expansion is isothermal, even though this is not strictly correct, as it affords us a standard which is far better than no standard at all.

Dr. Versluys invites us to apply the formula to which he has given mathematical expression, determining the constants by experiment. This idea, in principle, is correct, I believe, but in practice it is exceedingly difficult to carry out. Experiments covering a small range of lift up to 200 or 300 ft. are almost valueless for determining factors that apply to greater lifts such as obtain in almost all oil-field operations, consequently experiments on a laboratory scale do not provide us with data useful for

oil-field practice. It is usual to learn of gas-lifts being employed in oil fields where the depths are from 3000 to 5000 ft. or more, and in this practice, date of varying character appear to result. We know that air-lifts with inclination from the vertical give widely varying results from those that are vertical. In deep holes the variation from the vertical may be great, as we have recently learned. This inclination from the vertical may be an important reason for the variable results that appear to be obtained in air-lift work. The writer has attempted to introduce constants for the various factors of friction, slippage, viscosity, temperature, etc., so far with no degree of satisfaction, even though many thousands of observations have been carefully noted while making tests. This has led him to confine his calculations, for the present, to the standard obtained by basing the relation of foot-pounds of work in the gas at the bottom of the tubing to the foot-pounds of useful work in lifting the liquid to the discharge point, assuming the expansion to take place under isothermal conditions. As a rough guide, under these conditions, the percentage of efficiency should approximately equal the percentage of submergence with pipe of uniform diameter; where the percentage of submergence is high, the percentage of efficiency will be less than the percentage of submergence; where percentage of submergence is low, the efficiency may be as much as two or three times the percentage of submergence.

From a practical standpoint, the method of calculation noted by the writer appears to serve the purpose. From a mathematical point of view the treatment proposed by Dr. Versluys is interesting and well worth being followed up to a definite conclusion.

J. Versluys.—I am much indebted to Mr. Shaw for his discussion of my paper. In its entity he seems to agree to my ideas and his paper mainly is an explanation of some of my principles to the reader. There are only two questions in which there is a difference of opinion.

Mr. Shaw states that the percentage of the gas which is dissolved in the oil is small. The consequence of this idea would be that one of the formulas I deduced is superfluous; namely, the one including the effect of solubility of gas. I know, however, of a naturally flowing well in which at the pressure prevailing at the bottom, 20 per cent. of the gas must have been dissolved in the oil. Hence the solubility of the oil cannot be neglected in every case.

I cannot agree to Mr. Shaw's opinion that all the losses of energy must be treated separately. I have succeeded in bringing all energy—positive and negative—into one formula and I am of the opinion that this is the correct way to attack this problem. No solution of the problem can be obtained without such formula. This can be explained as follows. The drop of pressure in every section depends on the various resistances occurring in this section. But, on the other hand, all these resistances and the losses of energy depend on the velocity in the section. For instance, the turbulence resistance depends on the velocity, which means that it depends on the pressure that prevails. The same is true for the loss of energy due to slippage. This loss of energy depends on the velocity, and consequently on the pressure. So there is a mutual interference between all the sources of positive and negative energy in every cross-section and for that reason they should be included in one formula. Therefore, problems like the flow of oil and gas through a tubing can only be solved by the aid of higher mathematics.

We may consider the most simple question—how can we express the total turbulence resistance in a tubing if we do not know the velocity and the specific weight of the gas in every cross-section? Both depend on the pressure. So we must have at our disposal a formula which includes pressure and turbulence resistance. If more resistances interfere, they also have an influence on the drop of pressure, consequently on velocity and specific weight in the adjacent section and for this reason on the turbulence resistance.

Mr. Shaw speaks about the submergence. I purposely avoided this word because there is no real submergence. When the casinghead is closed and the casing is tight, there is no oil in the annular space. So the word submergence—which dates from days long before the gas-lift was used in oil wells and only the so-called mammoth pump was used in pumping from water-wells—can only cause confusion. There is no real submergence, but there is a certain pressure at the bottom of the tubing. Now then, because we have to do with pressure and a gas which is compressed, the available energy is proportional to the logarithm of the quotient of pressures at the bottom and the top of the tubing. This is the main source of energy. If for sake of simplicity we neglect the energy due to the pressure on the volume of oil which is lifted, we may say that the efficiency is:

$$\frac{\text{length of tubing} \times \text{weight of gas}}{\text{nat. log.} \times \dfrac{\text{pressure at bottom}}{\text{pressure at top}}}$$

but my assistant and friend, B. P. Boots, took the following more complete formula:

$$\frac{Q_v h_s}{100\left\{ Q_g lg \dfrac{p_c}{p_t} + Q_v(p_c - p_t) \right\}}$$

when,

h = tubing depth in meters.
s = specific weight of liquid.
Q_g = total volume of output gas at atmospheric pressure in cubic meters per day.
Q_v = total volume of liquid at atmospheric pressure in cubic meters per day.
p_c = pressure (absolute) at bottom of tubing in kg. per sq. cm.
p_t = same at top of tubing.

This formula can easily be checked with the formulas in my paper if these are integrated. Then the logarithm will appear in the denominator.

I believe the word submergence is misleading and on account of this one would be inclined to take pressure instead of its logarithm in the efficiency formula. This, however, is erroneous.

I will not elaborate further on the question of efficiency. On page 200 I warned against using the expression "efficiency" with respect to a gas-lift.

At the Tulsa meeting, October, 1929, I described how my experiments in Rumania are performed. A tubing 350 ft. long is run into an abandoned well. Gas and oil are put in through separate pipes at the bottom of the tubing and at distances of 70 ft. pressure and temperature are measured. Measurement of temperature is done electrically, measurement of pressure by manometers, while the drop of pressure on the distances of 70 ft. is ascertained by means of mercury differential manometers. I cannot agree with Mr. Shaw's opinion that this is wrong. As it appears from my formula, we have to know pressure and pressure differentials. In tubing lengths of 70 ft., drop of pressure is great enough to be indicated by the manometers. Moreover, because the volumes of oil and gas as well as pressure can be varied by means of valves at the bottom and at the top of the experimental tubing, we are at liberty to create any arbitrary gas-lift condition in this tubing. So, if desired, we could let the experimental tubing first give the pressure at the lower 350 ft. of a tubing, then by decreasing pressure let it act as the following length of 350 ft. of a tubing, if volumes of oil and gas are unaltered.

Flow Resistance of Gas-oil Mixtures through Vertical Pipes

By L. C. Uren,* P. P. Gregory,† R. A. Hancock† and G. V. Feskov,†
Berkeley, Calif.

(Tulsa Meeting and Los Angeles Meeting, October, 1929)

The resistance to flow of mixtures of gas and oil in passing up through the flow tubing of oil wells operated by gas-lift or by natural flow is a factor in oil-recovery technic that has received but little attention. Yet accurate design of a tubing installation for a particular set of conditions, where operation is by either of these methods, is impossible without quantitative data on the pressure loss suffered by the oil-gas mixture in its passage through the well tubing to the surface. Because of lack of such information, petroleum production technologists have been compelled to approach this problem by "cut-and-try" methods, which, doubtless in many cases, has resulted in the installation and use of tubing too large or too small for most efficient utilization of the expansive force of the gas used in lifting the oil. Impressed with the necessity for information of this character, the authors have conducted a series of tests with large-scale apparatus in the petroleum engineering laboratories of the University of California, designed to be productive of data that would afford a means of attacking the problem of flow-tubing design on a more scientific basis.

Mechanics of Expulsion of Gas-oil Mixtures in Naturally Flowing and Gas-lift Wells

When oil is lifted from a well by the expansive force of compressed natural gas or air, the fluids enter the lower end of the eduction tube under elevated pressure, with the gas partly in solution, but largely distributed in the form of occluded bubbles within the oil mass. As discharged from deep wells, after reaching the surface, there will normally be at least 60 times as much gas, by volume, as of oil; and in many cases the ratio of gas volume to that of the oil will have a value as great as 1000 or more. On entering the lower end of the eduction tube, however, a relatively smaller volume of gas will be found in the oil-gas mixture, on account of compression of the gas in accordance with the elevated pressure necessary. If the pressure at the point of admission to the

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eduction tube were, say, 300 lb. per sq. in., the relative volume of the gas to that of the oil at that point would range from a minimum of approximately 3 to 1 to 50 to 1, or higher. In all cases we are dealing with gas-oil mixtures in which the volume of gas is materially greater than that of the oil.

The mixture enters the lower end of the eduction tube with the ratio of gas volume to oil volume at a minimum value for the conditions

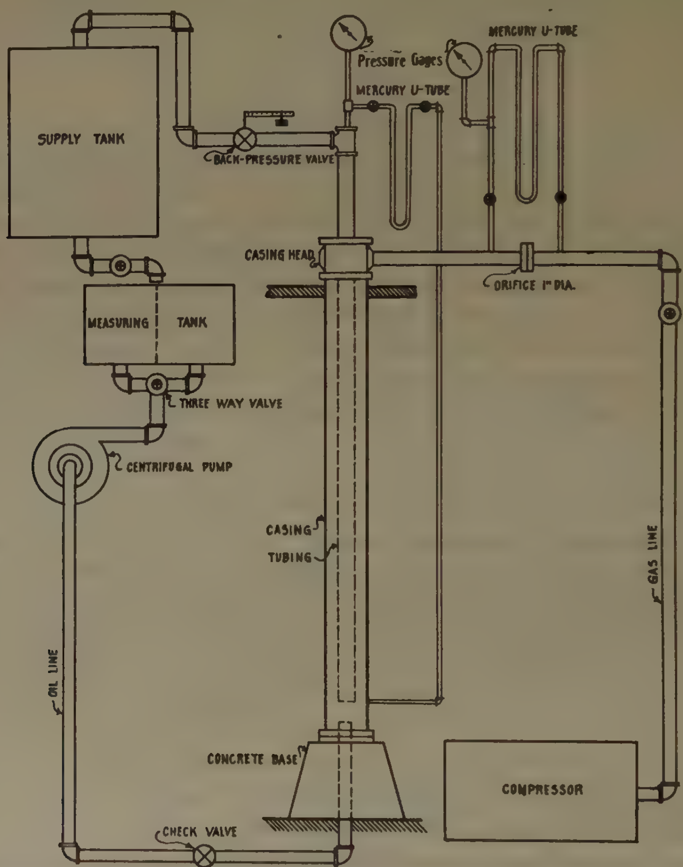

FIG. 1.—DIAGRAM OF APPARATUS FOR DETERMINATION OF RESISTANCE TO FLOW OF GAS-OIL MIXTURES.

existing; but as the fluid mixture rises, the pressure diminishes and the gas expands. The ratio of gas volume to oil volume is therefore continually increasing as the fluids rise, reaching a maximum at the surface, where the pressure is lowest. Such gas as exists in solution at the higher pressures is released on reduction of pressure, assuming the gaseous phase and further adding to the rapidly growing volume of fluid passing upward through the eduction tube.

Since the volume of fluids passing up through the eduction tube rapidly increases as the pressure is released, it follows that if the tube is of the same diameter throughout, the velocity of flow must continually increase, being a minimum at the bottom and reaching a maximum value at the top. Computations based on operating conditions in typical naturally flowing and gas-lift wells, in which flow occurs through tubing of from 2 to 4 in. dia., show flow velocities ranging from a few to many hundred feet per second.

The character of flow through the eduction tube is doubtless turbulent, it being inconceivable that viscous flow could exist within a nonhomogeneous fluid mass moving through a tube of restricted cross-section at such high velocities.

As gas expands, it suffers a definite loss in temperature. Expansion of gas within the eduction tube is not adiabatic, however, as the oil—within which the gas is occluded—the walls of the tubing and the surrounding rock masses offer a reservoir of heat ready largely to make up loss in temperature, which would otherwise result through gas expansion. Expansion of the gas is probably nearer isothermal than adiabatic.

Energy released by expansion of gas as it rises through the eduction tube is applied in two ways: (1) in lifting the fluid mass, and (2) in overcoming frictional resistance to flow. The flow resistance is made up of two components: (a) frictional resistance against the walls of the tube, and (b) internal friction within the fluid mass in adjusting itself to the rapidly increasing gas volume, and the fluid friction of gas-oil surfaces in turbulent flow.

Variables Influencing Pressure Loss in Flow of Fluids through Pipes

In approaching the problem of evaluating and formulating the variables influencing pressure loss, the authors have assumed that the Fanning formula would comprise all of the variables involved. This formula has been demonstrated to have a wide range of application, including computations of pressure loss of oils and gases through pipes.[1] The several variables involved are related as follows:

$$P = \frac{0.323\,fLSV^2}{D}, \text{ in which}$$

P is the pressure loss (in pounds per square inch) sustained by a fluid of specific gravity S, in moving through a pipe of internal diameter D (in inches) and length L (in feet), at velocity V (in feet per second). The friction factor f is a function of the product of the pipe diameter D, the flow velocity V, and the specific gravity S, divided by the viscosity

[1] R. E. Wilson, W. H. McAdams and M. Seltzer: The Flow of Fluids through Commercial Pipe Lines. *Jnl. of Ind. & Eng. Chem.* (1922) **14**, 105.

Z, which may be conveniently expressed in centipoises; that is, f varies as the value of the expression $\frac{DVS}{Z}$. It appears that if the value of f is arbitrarily made equal to $0.00207 \times \frac{Z}{DVS}$, the Fanning formula becomes equivalent to the Poiseuille formula, in which

$$P = \frac{0.000668ZLV}{D^2}$$

and holds true over the entire range of turbulent and viscous flow.

These expressions have been used in computing the values of f, the friction factor in the Fanning equation, and Z, the absolute viscosity for various gas-oil mixtures, from observed data assembled in the course of the experimental tests described below. Values for P, the pressure loss, were experimentally determined for many different measured flow velocities, V, in a pipe of known diameter D and length L. Values of S, the specific gravity, for different gas-oil mixtures, were computed from the known specific gravities of the oil and gas used and the percentages of each in the oil-gas mixtures. With all variables in the Fanning formula, except f, experimentally measured or computed, it has been possible to solve directly for values of f. Knowing the values of f, D, V and S, it has also been possible to compute corresponding values for the absolute viscosities of the gas-oil mixtures used.

Apparatus Used in Flow Tests

The apparatus used in making the pressure-loss tests is illustrated diagrammatically in Fig. 1. The "well" consists of a vertical column of 5½-in. casing, 42 ft. high, the lower end being supported on a concrete pedestal and closed by a blind flange except for a short 2-in. pipe, which penetrates the flange and pedestal from below. A column of 2-in. oil-well tubing 41.4 ft. long is suspended within the casing from a gastight casinghead, the lower open end of the tubing being about 2 ft. off bottom. This serves as the eduction tube.

A 25-bbl. tank provides storage for surplus oil above the casinghead. From this tank, oil flows—with suitable valve control—into a gaging tank having two compartments, each of 1½-bbl. capacity. A swing connection permits of alternately diverting the oil flow to one or the other of the two compartments, one filling as the other is emptied. From either of the two compartments of the gaging tank, oil is taken through a three-way valve into the suction line of a small centrifugal pump which discharges it under pressure, into the lower end of the vertical column of 5½-in. casing.

A supply of compressed air is available, which is led into one of the side outlets of the casinghead, thence down through the annular space

between the tubing and casing to the lower end of the tubing, where it meets the ascending stream of oil, both fluids simultaneously entering the open, lower end of the eduction tube, where they become intimately mixed. The volume and pressure of the air used is recorded with the aid of an orifice meter equipped with appropriate differential and static pressure gages. The oil-gas mixture, after rising through the eduction tube, is discharged through an adjustable back-pressure valve, into the 25-bbl. storage tank, where the fluids come to rest for a sufficient time to allow all the air to escape from the oil.

Means are thus provided for accurately measuring the volume of oil and the volume and pressure of air entering and passing through the eduction tube at any time. Pressure conditions at the lower end of the eduction tube, and the ratio of gas to oil in the mixture, may be altered within a considerable range by adjusting the speed of the centrifugal pump and the pressure and volume of air passing the orifice meter. The pressure under which the gas-oil mixture is discharged at the upper end of the eduction tube may also be varied within limits by adjusting the weight-and-lever control on the back-pressure valve.

In order to measure the pressure loss between the lower and upper ends of the eduction tube, a ¼-in. pipe is tapped into the 5½-in. casing, opposite the lower end of the tubing, while a second connection is made directly into the upper end of the tubing. These tubes communicate with opposite legs of a mercury manometer and the differential pressure between the two ends of the eduction tube is thus indicated. A spring pressure gage also records the static pressure at the upper end of the column.

Manipulation of Equipment in Conduct of Tests

In starting a "run," both sections of the measuring tank are filled with oil from the supply tank, then air is turned into the casinghead and the back-pressure valve is adjusted to give the desired discharge pressure. When the flow of air becomes uniform, one section of the measuring tank is connected with the pump suction and the pump is started, allowing the oil to flow into the bottom of the "well," the speed of the pump being adjusted to provide the desired rate of oil flow.

The lift is now operating, a mixture of air and oil rising through the eduction tube and discharging into the storage tank. As soon as flow conditions have reached equilibrium, the oil in the full section of the measuring tank is gaged. Because of the short lift, only a few minutes are necessary to establish a condition of uniform flow. By means of the three-way valve, the full section of the tank is now "cut in" and flow continued until this section is nearly emptied, when it is again gaged. The two gages provide an exact measure of the quantity of oil used in the run. Readings are taken of the pressure gages and manom-

eter at intervals during the run. The differential pressure between the top and bottom of the tubing gives the pressure drop for the particular conditions prevailing, and the quantity of air used is computed from the static and differential pressures on the orifice-meter gages.

Properties of Oil Used

The oil used in these tests was a residuum fuel oil having an A.P.I. gravity of 18.3°, and a Saybolt Furol viscosity of 270 sec. at the test temperature, which remained practically constant throughout the entire series of tests.

Results of Tests

One hundred separate runs were made, under a wide variety of conditions, providing air-oil ratios ranging from 520 to 7050 and flow

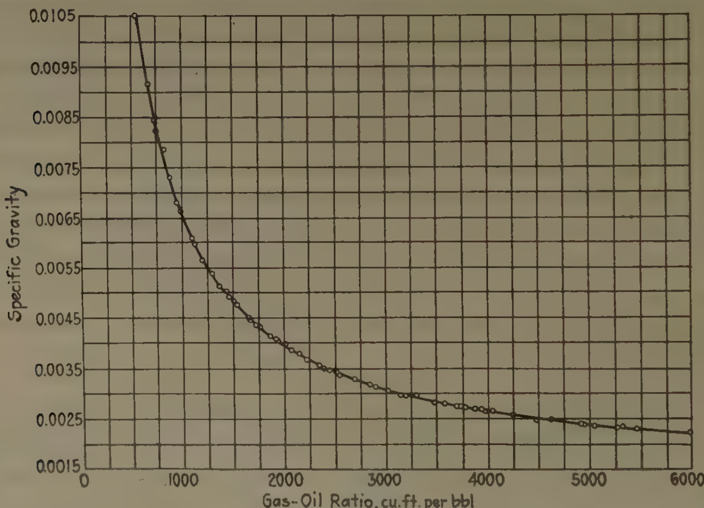

Fig. 2.—Variation of specific gravity of air-oil mixtures with different gas-oil ratios.

velocities in the eduction tube ranging from 35 to 108 ft. per sec. The pressure loss was found to range from 0.109 to 0.356 lb. per sq. in. per linear foot of flow. The Fanning equation friction factor and the viscosity of the air-oil mixture were computed for each run. The reader will not be burdened with tabulated data and details of the computations. Instead, the authors have adopted the plan of using graphs for displaying the results of the tests and the relationships found to exist between the several variables controlling pressure loss. These graphs are presented in Figs. 2 to 7 herewith.

Fig. 2 displays the computed variation in specific gravity for air-oil mixtures ranging from 500 to 6000 cu. ft. of air per barrel of oil. The

density of air is here taken as 0.0013 and that of the oil as 0.94. The graph shows the value of S in the Fanning formula for the particular oil and gas used throughout the tests.

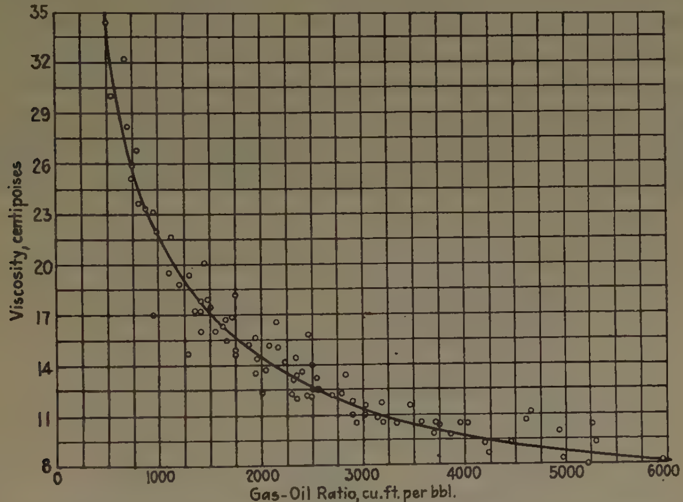

FIG. 3.—VARIATION OF VISCOSITY OF AIR-OIL MIXTURES FOR DIFFERENT GAS-OIL RATIOS.

Fig. 3 shows how the computed values of absolute viscosity of air-oil mixtures diminish as the air-oil ratio increases. Important reductions in viscosity are secured by increasing the percentage of air in the mixture. This tends to reduce the frictional loss in moving the fluid through the

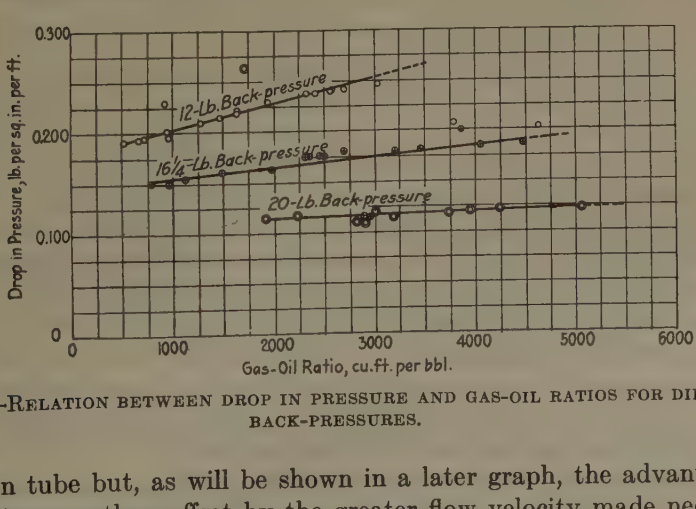

FIG. 4.—RELATION BETWEEN DROP IN PRESSURE AND GAS-OIL RATIOS FOR DIFFERENT BACK-PRESSURES.

eduction tube but, as will be shown in a later graph, the advantage so gained is more than offset by the greater flow velocity made necessary by increased volume of fluid to be handled.

The three graphs of Fig. 4 demonstrate that a straight-line relationship exists between the loss in pressure and the air-oil ratio, the pressure loss per linear foot of tubing traversed increasing directly as the volume of air in the fluid mixture increases. It seems probable that this relationship does not exist over the entire range of possible mixtures, the data indicating that at a ratio of between 300 and 500 there is a critical inflection point at which a reversal in the slope of the graphs will occur, the flow resistance increasing below this critical point as the air-oil ratio diminishes. The reason for this change in the characteristics of the graphs is found in the fact that the loss in pressure is controlled

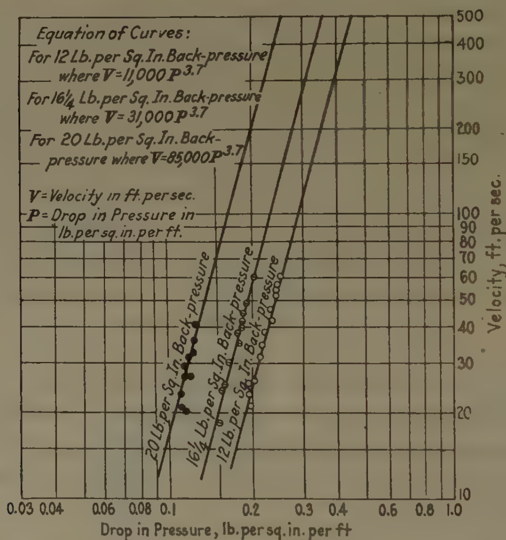

FIG. 5.—RELATION BETWEEN DROP IN PRESSURE AND VELOCITY FOR DIFFERENT BACK-PRESSURES.

primarily by three variables: namely, flow velocity, density and viscosity of the air-oil mixture. At low gas-oil ratios, governing factors are the reductions in specific gravity and viscosity of the mixture, which act in a direction opposite to that of increased flow velocity. It is estimated, for the conditions presented in these tests, that at a value of between 300 and 500 for the air-oil ratio the three factors will determine a point of minimum flow resistance. It is regrettable that the tests could not be conducted at ratios low enough to determine this point experimentally, but it is interesting to note that it lies considerably below the range of gas-oil ratios normally attained in field practice.

Fig. 4 also brings out the interesting fact that the pressure loss per unit of linear travel through the eduction tube is less at high pressures than at low pressures for a given gas-oil ratio. This, of course, is caused

by the smaller volume of the gas at elevated pressure, with consequently lower velocity of flow for the fluid mixture.

The effect of flow velocity of gas-oil mixtures on pressure loss is also well demonstrated by Fig. 5, in which the experimentally measured pressure loss of air-oil mixtures, for a wide range of computed flow velocities, is shown for three different conditions of back-pressure. These graphs are of logarithmic type; hence, when plotted on logarithmic coordinates, they become straight lines. It has been possible therefore to extrapolate the graphs in both directions beyond the range of the experimental values. These graphs again indicate increased pressure loss with increased flow velocity, and lower unit pressure losses at the same flow velocity for higher fluid pressures. This can only result

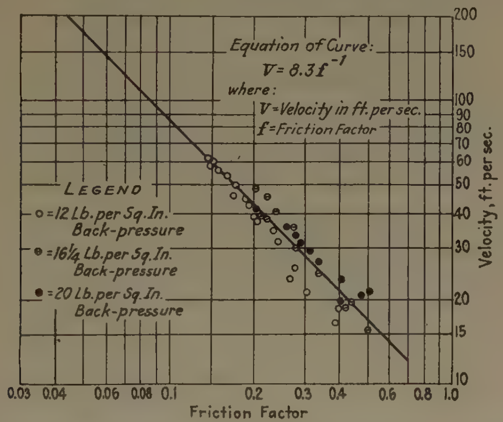

FIG. 6.—RELATION BETWEEN FRICTION FACTOR AND VELOCITY.

through diminished viscosity and density, which is attained by higher percentages of gas in the fluid (computed as free gas) at the higher pressures.

The relationship existing between flow velocity and the friction factor f, of the Fanning equation, is indicated in the graph of Fig. 6, which is also of logarithmic type. It will be observed that values for the tests conducted at three different back-pressures fall approximately on a straight line. In other words, this relationship is independent of the pressure. These values for the friction factor are, of course, appropriate only for the conditions applying in the tests from which the data are derived.

The graph reproduced in Fig. 7, however, should be of general application. Here values for the expression $\frac{DVS}{Z}$ are plotted against corresponding values of the friction factor f in the Fanning equation. The computed values of f again indicate a logarithmic relationship. From the graph of Fig. 7, it should be possible to find an appropriate value

for the friction factor for any assumed values of the controlling factors, D, V, S, and Z, and directly apply the Fanning equation to determine pressure loss. This relationship should hold true for pipe diameters and oil properties differing from those used in the experimental tests, but one must necessarily know the viscosity and density of the gas-oil mixture used in each case. The density of the mixture could be readily computed if those of the oil and the gas and the ratio of both in the mixture were known (as in Fig. 2). The viscosity of an oil-gas mixture could probably only be arrived at by experimental tests, leading to results comparable with those reproduced in Fig. 3; that is, an oil differing

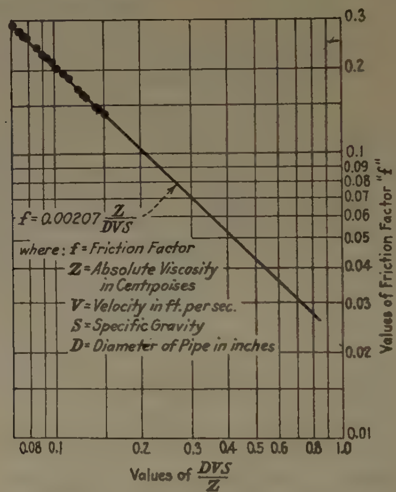

FIG. 7.—VALUES OF FRICTION FACTOR IN THE FANNING EQUATION FOR DIFFERENT VALUES OF FLUID VISCOSITY AND DENSITY, DIAMETER OF PIPE AND FLOW VELOCITY.

in viscosity from that used in the tests, results of which are herein reported, would necessarily produce a different graph for the relation between gas-oil ratio and viscosity, though perhaps one comparable in general characteristics with that reproduced in Fig. 3. Absence of such data suggests a line of research which, when completed, will make the data presented in this paper of more general application.

Use of the Fanning equation in computing the flow variables in this way is perhaps open to criticism on the ground that the gas-oil mixtures dealt with are not homogeneous fluids and that the assumptions made do not take slippage of gas through the oil into account. These are valid criticisms, but the apparent regularity in relationship of the several variables throughout the tests leads to the belief that they are not important factors in determining flow resistance under the conditions presented in these tests.

Summary and Conclusions

While not productive of sufficient data to provide a means of computing pressure loss of flowing gas-oil mixtures under all conditions presented in field practice, the tests described herein at least suggest a method of approach in reaching a workable solution of an important engineering problem. Continued experimentation along the lines followed in this research will, it is hoped, provide a fund of data from which the flow resistance of gas-oil mixtures under any conditions—actual or assumed—may be closely estimated.

While the data thus far assembled are inadequate to completely define the flow characteristics under all conditions, at least they permit of certain conclusions that will be of general application:

1. The density and viscosity of gas-oil mixtures vary as logarithmic functions of the gas-oil ratio.
2. Within the range of gas-oil mixtures commonly produced from flowing and gas-lift wells, increase in the volume ratio of gas to that of oil, at a given pressure, results in increased pressure loss per linear unit of flow through the eduction tube.
3. Increase in pressure for a given gas-oil ratio or a given flow velocity is productive of decreased unit pressure loss. A given gas-oil mixture is therefore moved with lower unit pressure loss through the lower part of an eduction tube, where the pressure is high, than through the upper part, where the pressure is comparatively low.
4. A critical gas-oil ratio probably exists for any set of conditions, at which the pressure loss in flow through tubing is a minimum; but this most efficient ratio is probably lower than gas-oil ratios realized in present-day oil-well operation.
5. In applying the Fanning equation to the flow of gas-oil mixtures through vertical pipes, the friction factor f is found to be a logarithmic function of the expression $\frac{DVS}{Z}$.

Some Observations on Principles Involved in Flowing Oil Wells

By S. F. Shaw,* Tulsa, Okla.

(Tulsa Meeting, October, 1929)

The principles involved in lifting oil in wells flowing naturally are identical with those underlying the flowing of wells by means of the air-gas lift, and information of a dependable nature obtained in the study of the air-lift can be applied to wells with natural flow. A well flowing naturally is one in which the lifting is done by means of the gas-lift, for which the gas is supplied entirely by the formation from which the oil is derived. In air-gas lift operations, there is insufficient gas supplied by the formation to lift the oil to the surface in an efficient manner, therefore additional gas for this purpose must be furnished from an outside source.

There may, at times, be conditions obtaining in natural flowing wells different from those in wells flowed by gas-lift, but these differences do not at all conflict with the main principles of gas-lift work. One such condition is met with in wells in which the gas supplied by the formation is in considerable excess of that required to lift the oil to surface; this excess may be so great as to reduce the quantity of oil that can be lifted through the particular diameter of casing or tubing that has been lowered into the well. This same condition can be brought about, however, by supplying a large excess of gas from an outside source to an artificial gas-lift well, and a study of the effects obtained from injecting a large excess into the well can be applied directly to handling wells flowing naturally which have a large excess of gas supplied by the underground reservoir.

Conditions for Lifting Oil

The main factors to be considered in flowing wells are as follows:

1. Submergence, or pressure at the bottom of the tubing or casing.
2. Lift; the height to which the liquid must be raised.
3. Diameter of the flow tubing or casing.
4. Quantity of liquid to be lifted.
5. Pressure at the discharge end of the flow tubing, or back-pressure, as it is sometimes called.

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* Consulting Engineer, Carter Oil Co.

6. Temperature of the liquid.
7. Viscosity of the liquid.

Submergence

In air-lift work, a liquid is lifted by the energy stored in gas under pressure; energy that is given out because the gas expands. If the gas is not under pressure it can do no work, therefore at the lower end of the tubing it must be under a pressure greater than the pressure that exists at the top of the tubing. The measure of the energy is determined by the differences in pressure existing at the bottom and at the top of the tubing, and the pressure to which the gas can be compressed at the lower end of the tubing is determined by the submergence. In other words, the greater the submergence, the greater will be the pressure under which the gas can exist, and the greater will be the work that can be done by a unit quantity of gas. The smaller the quantity of gas containing a given quantity of work, the less will be the friction loss set up by this gas in flowing through the tubing. We have found in practice that the greater the submergence, the greater is the lifting efficiency. In general, we might say that good work is not being done unless the percentage of efficiency is equal to, or greater than, the percentage of submergence.

Lift and Diameter of Tubing

The distance that the fluid is lifted above the existing level of the liquid is called the lift. The work required to lift a unit quantity of liquid varies directly as the lift; that is, to lift a unit quantity of liquid 200 ft. will require the expenditure of twice the work that will be required to lift this unit quantity of liquid 100 feet.

Changes in the diameter of the flow tubing will have marked effect on the performance of a gas-lift. In general, we may say that, other conditions remaining the same, increase in diameter of the tubing will permit a greater quantity of liquid to be lifted. However, if there is a given quantity of liquid to be lifted, which cannot be varied at will, there is a given diameter of tubing that will make for the maximum efficiency.

The quantity of liquid to be lifted will determine the diameter of tubing to be used, and will also determine the quantity of gas necessary to lift that given quantity of liquid. Where large diameters of tubing are required, the lifting efficiency will be greater than in wells requiring small diameters of tubing.

Pressure

In general, we may say that the lower the pressure that exists at the discharge end of the tubing, the greater will be the lifting efficiency obtained. Back-pressures are sometimes employed, and sometimes

beneficial results are obtained, but probably injurious effects are more often the result. If a well requires that gas be admitted from the compressor in order to lift the liquid, it can almost always be said that back-pressures at the top of the tubing lower the efficiency. A set of conditions may exist, however, in a well flowing naturally, where there is a large excess of gas present with the oil, and where the tubing is of such size that unless a back-pressure is applied at the top there will be an excessive friction loss in passing through the tubing. In such a case, it may be possible that a back-pressure applied at the top will reduce the friction loss and lower the back-pressure at the bottom of the well, and therefore allow a greater quantity of oil to be lifted through the tubing.

Temperature and Viscosity of Liquid

Raising the temperature of the liquid will make the oil thinner, thereby lowering the viscosity and consequently lowering the friction loss of oil passing through the tubing. Instances are known where the heating of the input gas has increased the quantity of liquid being lifted, and this without varying any of the other conditions of operation. It seems possible that the temperature of the oil in the pool may have a marked effect on the facility with which the oil will pass through the sand in reaching the well, possibly in many cases a greater effect than that caused by lowering of the viscosity by high pressures.

The viscosity of the liquid being lifted appears to have a marked effect, although the direct application of viscosity factors to lifting efficiencies cannot be made at present on account of the almost complete lack of definite information on this subject. The writer once had occasion to lift oil of 22.5° Bé. gravity under conditions that required the expenditure of 2000 cu. ft. of gas per bbl.; under the same conditions of lift, diameter of pipe, etc., but with oil of 37.5° Bé. gravity, there was required 1100 cu. ft. per bbl. So far as the writer was able to ascertain, this great difference in consumption of gas was caused by the difference in viscosity of the oils being lifted.

It may be said in general that, with other conditions remaining unchanged, the quantity of liquid being lifted will vary directly as some function of the submergence and of the diameter of the tubing; and will vary inversely as some function of the lift, of the discharge pressure, and of the viscosity of oil.

Significant Points of Production

In all lifting operations, there are four significant points of production that can be obtained in a tubing of given design, whether that design be efficient or not, as follows:

1. Point of no flow caused by deficiency of gas. This is the point where the amount of gas passing through the tubing is just insufficient to lift liquid, but where, if any more gas be added, a flow will start. In a tapered tubing, 1000 ft. long, 7 in. dia. at the bottom and 10 in. at the top, it was found that 1000 cu. ft. of air per minute would not lift any liquid, but when the air was increased beyond this quantity the flow of water would start in small quantity.

2. Point of maximum efficiency. This point for any given tubing design is the point which gives the maximum lifting efficiency for any given set of conditions.

3. Point of maximum capacity. For any given set of conditions, there is a definite maximum capacity which it is impossible to exceed.

4. Point of no flow caused by excess of gas. In any given tubing design it is possible to admit so much gas that there will be no flow of liquid. In other words, the friction loss of this excessive quantity of gas passing through the tubing is equal to the submergence pressure.

Control of Gas-oil Ratio

In a flowing well, the gas-lift factor, or cubic feet of gas required to lift a barrel of oil, is identical with the gas-oil ratio. In artificial gas-lift operations, the gas-oil ratio is the difference between the gas-lift factor and the gas-input factor. The gas-oil ratio may be altered considerably by the quantity of input gas admitted to the well, or, in other words, by the manner in which the well is operated. The gas-oil ratio in artificial gas-lift operations may be controlled within certain limits by any one or more of the following operations:

1. Changing the submergence.
2. Changing the lift.
3. Changing the diameter or design of the flow tubing.
4. Changing the quantity being lifted.
5. Changing the temperature.
6. Changing the pressure at the discharge.

In gas-lift operations it is possible to make changes in any or possibly all of these factors. The most important change lying within the control of the engineer is that of tubing design. In wells flowing naturally, with a given tubing design, change can be made in submergence, in the lift, and in the quantity of liquid being lifted, by use of beans or flow nipples. Changes of tubing design can sometimes be made in wells flowing naturally, though in many cases this change is attended with considerable difficulty, and unless the engineer is practically certain that he knows just what change of tubing will be beneficial, he is reluctant to make any change at all.

Considerable care should be taken to insure correct measurements of gas. Often the flowing of wells under back-pressure causes considerable

gas to be carried along dissolved in or occluded with the oil as it goes to the receiving tanks, and as this gas is not measured, incorrect gas-oil ratios may result. Much care should be exercised to insure conditions of gas measurement that shall be similar, or according to similar standards, else comparisons of gas-oil ratios are likely to be confusing and perhaps contradictory.

A careful study of the various factors involved is necessary before the engineer can handle artificial gas-lift operations with any degree of success. This study will be of the greatest benefit when he attempts to handle wells flowing naturally.

DISCUSSION

E. H. Griswold,* Ponca City, Okla.—Mr. Shaw has given a good review of the gas-lift principles of flowing wells. One point in which I was particularly interested was the note on the difference in the rate of flow effected by the viscosity of the oil.

In measuring gas-oil ratios, it has been our custom in the experiments which were started a few years ago, to apply a minimum constant back-pressure on the separator and vary the pressure on the well by means of chokes or gates. By this means, our measurements were kept accurate, as there was no danger of varying amounts of gas being dissolved in the oil and passing out through the trap dump valve.

Our experience coincides with that of Mr. Shaw—it may be possible that back-pressure at the top of the well may reduce the pressure applied to the formation at the bottom. The only explanation I can give for this phenomenon is the condensation of vapors because of the added back-pressure, and therefore a decrease in the pressure loss due to velocity and frictional effects.

I would take issue with Mr. Shaw's paper in regard to his comments regarding the Wilcox sand production in Seminole. We have found that in some Wilcox sand wells in the Seminole area the best results are obtained with the minimum pressure in the bottom of the well, but in many cases we found that an increased back-pressure in the bottom of the well not only decreased gas-oil ratios but actually increased production.

Another point worthy of mention is that when tubing is run in a natural flowing well, it is often spoken of as being used to restrict the flow. Often the exact reverse effect is obtained; *i. e.*, the installation of tubing in many flowing wells decreases the effective back-pressure at the bottom. If this were not true some other explanation must be found for the many wells that will flow naturally through tubing but will not flow through the casing.

Regarding the matter of gas-lifting efficiency in a flowing well, we feel that three other conditions supersede lifting efficiency in importance—production from the sand into the well, minimum gas-oil ratio and operating costs. We endeavor to adjust the pressure in the bottom of the well to satisfy the first two conditions and gas-lift the well in such a manner that the desired pressure is obtained in the bottom of the hole at a reasonable operating cost. In other words, we concentrate our efforts on the flow into the well, rather than the flow from the bottom of the well to the top.

J. R. McWilliams,† Tulsa, Okla.—Applying back-pressure at the top of a flow string may under certain conditions cause a decrease in pressure at the bottom of the

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† Petroleum Engineer, Skelly Oil Co.

flow string with an increase in oil production; however, I do not attribute the increase in oil production to the small decrease in bottom-hole pressure but rather to the fact that the back-pressure applied at the top causes a decrease in the velocity of the gas in the upper portion of the flow string. In other words, for each size of flow string there is a maximum velocity which should not be exceeded if maximum oil is produced through it. If this excessive velocity is present in the top of a flow string, back-pressure can be applied to reduce it.

W. P. Haseman,* Oklahoma City, Okla.—The effective size of the gas bubbles in the flow stream is a factor which affects the efficiency of the flow and therefore the lift. The primary function of the gas is to aerate the liquid column while the fluid pressure lifts the liquid. The flow should be more efficient if the parts of the stream move together as a homogeneous fluid. A condition may exist where the gas is flowing up through the center and the oil up along the sides of the tubing.

The buoyant force on a submerged bubble is proportional to the volume, while the viscous drag is proportional to the surface of the bubble. When you put "back-pressure" on a well you decrease the buoyant force faster than the viscous dragging effect. The gas-oil ratio would therefore be decreased. An increasing "back-pressure" will continue to decrease the size of the gas bubbles and also decrease the velocity of the fluid stream. A certain critical velocity for the fluid column would soon be reached where the gas bubbles again move faster than the liquid and the gas-oil ratio increases.

I. I. Gardescu,† Pittsburgh, Pa.—Gas bubbles in motion do not remain spherical. Their shape becomes ellipsoidal, with the long axis alternately being oriented horizontally and vertically. The bubbles vibrate around their spherical position of equilibrium. F. T. Trouton, in a report presented at a meeting of the British Association for the Advancement in Science, in 1892, shows that the velocity of ascending bubbles in a vertical column of liquid is a *periodical* function of the size of the bubble. The variation in velocity due to the vibration of the bubbles might cause some slipping of the gas bubbles with regard to oil. Also, the velocity of ascending gas bubbles, being a periodic function of their size, calls for a finer adjustment of the pressure in the flow pipe, which would affect the size of the gas bubbles and possibly give a more efficient and desirable rate of ascent.

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* Consulting Engineer.

† Petroleum Engineer, Research Department, Gulf Production Co.

Classification of Flowing Wells with Respect to Velocity

By F. P. Donohue,* Fort Worth, Texas

(Tulsa Meeting, October, 1929)

The observations and data presented in this paper are the result of extensive study of flowing wells, most of which were in the Maracaibo Lake Basin of Venezuela. The Lago Petroleum Corpn. had extensive production in this area, gas-oil ratios were low, and the problem was to determine whether by careful handling of the wells with respect to flowing conditions and by conserving the gas, the oil production of the wells could be maintained by natural flow until it had declined to a rate which could be handled with an ordinary working barrel, thereby avoiding the high cost of gas-lift equipment installation in the lake bed. The problem was complicated by the nature of the wells themselves. Production is from soft, comparatively unconsolidated sands, necessitating screen pipe in all wells. It was not only necessary to keep the wells flowing but to keep them flowing without heading, as the release of pressure upon making a head brought large quantities of sand into the wells, sanding them up or possibly cutting out the screen pipe. In furtherance of the plan of keeping wells flowing as long as possible, each well was equipped with a casinghead and tubinghead recording pressure gage, and an oil and gas separator set. About one-half of the wells were equipped with gas meters. All wells were tubed before bringing into production. Frequently individual gages were taken on each well. A large scale chart was plotted for each well, showing daily oil production, gas production, gas-oil ratio, tubinghead pressure and casinghead pressure. Any deviation from the normal was immediately checked and the condition remedied if possible.

Theory of Flowing Wells

Based upon considerable study of these records, it is believed that the flow of a well actuated by gas is mainly a problem in velocity, a certain minimum velocity in the flow string being necessary for the gas to carry the oil. If this minimum velocity is not obtained the oil drops back and the well heads or goes dead. The point of minimum velocity is of course at the bottom of the tubing, where the gas is under the highest pressure and therefore occupies the least volume.

Some years ago when the success of the gas-lift at Seminole was so pronounced, there was considerable broadcasting of the statement that

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a well had three stages of life—the flowing stage, the gas-lift stage and the pumping stage. The theory of the gas-lift stage was based upon the fact that natural flow was usually followed by a heading period, this heading being supposed to be due to decline of pressure in the reservoir, or decline in the gas-oil ratio, or other causes. However, gas-oil ratios usually increase with the life of the well up to a certain point. The fact seems to have been almost completely overlooked that as a well declined in production, even with an increase of the gas-oil ratio, there was a decline of total volume of oil and gas which diminished the velocity in the flow string and that the velocity might be correlated with the well's flowing life.

The Amerada Petroleum Corpn. had a flowing well in Central Texas, upon which it was decided to experiment. The well had been completed with $5\frac{3}{16}$-in. casing with an initial production of 500 bbl. per day. It declined to about 300 bbl., started heading and died. According to the old theory it now needed artificial help to flow. However, it was decided to try out the velocity theory. Upon running a string of 3-in. tubing and giving one pull of the swab to lighten the fluid load, the well resumed steady flow. When the velocity at the bottom of the 3-in. tubing approximated 5 ft. per sec. heading again occurred and the well died. Two and one-half inch tubing was then run and the well flowed again until the velocity approached 5 ft. per sec. Then 2-in. tubing and later 1.5-in. were run, the well finally dying in the 1.5-in. at 60 bbl. per day, which had a minimum velocity of about 5 ft. per sec. Since then 1-in. tubing has been used in Venezuela, the well flowing quite steadily at 15 bbl. per day.

Further experimentation upon flowing wells has made it apparent that velocity at the bottom of the flow string is the main controlling factor in the flow of oil wells flowing by gas. This velocity varies with the viscosity and the other characteristics of the oil—in one Venezuelan heavy-oil field the velocity is only 1.5 ft. per sec. In other fields where the oil is considerably less viscous, the minimum velocity is between 4 and 5 ft. per sec. Repeatedly it has been found that wells showing a tendency to head were at this critical velocity and that by enlarging the choke, thereby permitting the gas to expand, occupying greater volume and increasing the velocity, the heading disappeared. On the other hand, it has been found that wells which flowed steadily began to head as soon as choked to that point where the flowing velocity approached the minimum critical velocity of 5 ft. per second.

Pulsating Wells

We were trying to do two things with the wells in Venezuela. First, it was desired to keep the wells flowing until production declined to a rate that could be handled with a pump and the installation of gas-lift

equipment avoided. Second, it was necessary to keep the wells flowing without heading to avoid injuring the wells by pulling in excessive sand. The first type of well investigated was what was termed a pulsating or surging well. (Fig. 1.) In these wells the casinghead pressure was constant but the tubinghead pressure fluctuated in short interval. This was due to separation of oil and gas within the flow string, the oil building up the tubinghead pressure as it went through in slugs. As the casinghead pressure, the indicator of pressure on the face of the sand, was regular,

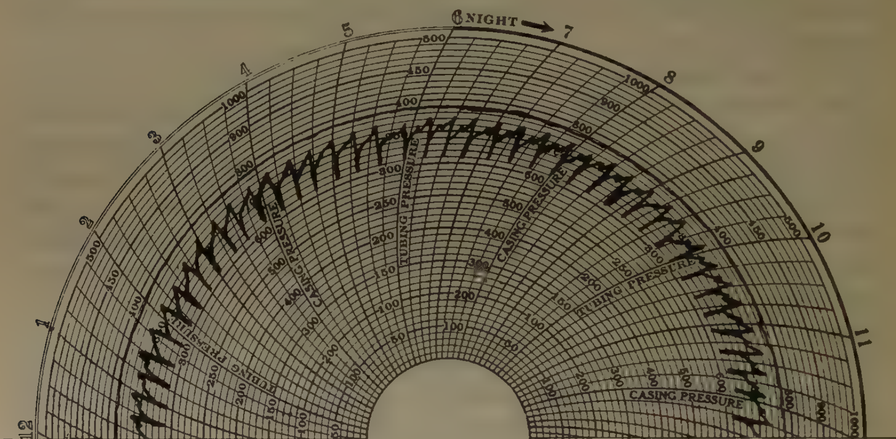

Fig. 1.—Typical surging well.

Note 50-lb. surge at tubinghead with almost steady casinghead pressure. This well is very close to passing over into heading stage as shown in Fig. 3.

these wells were allowed to go on in this fashion as no harm was being done by the separation in the tubing.

Wells with Excessive Tubing Velocities

The next type of well encountered was that which while flowing practically steadily made four or five heads during the 24-hr. period superimposed upon the steady flow. Investigation showed that the oil in these wells was very viscous, and that tubing velocities ran as high as 20 ft. per sec., excessive for wells of this viscosity. What was occurring was that due to the size of tubing used, 2.5 in., there was insufficient venting area for such a viscous oil. (Fig. 2.) Pressure accumulated in the casing behind the tubing, cutting down production due to increased back-pressure, until that pressure became so great as to clean the tubing. This accounts for the four or five heads imposed on the steady flow.

Since excessive velocity was evidently the cause, an attempt was made to turn the flow through the annular space between the tubing and the casing. This space, 8¼ by 3 in., was too great, however, and

the wells would not flow. They were therefore turned back through the tubing and sufficient gas bled off through the casinghead to reduce the velocity through the tubing. The wells thereupon stopped these heads. Some of the wells, however, made some oil through the casing, and as this was undesirable the casingheads on these wells were shut in and the wells allowed to continue heading. As soon as these wells had declined in production to such a point that their flow velocities approached normal, they also stopped heading and flowed normally.

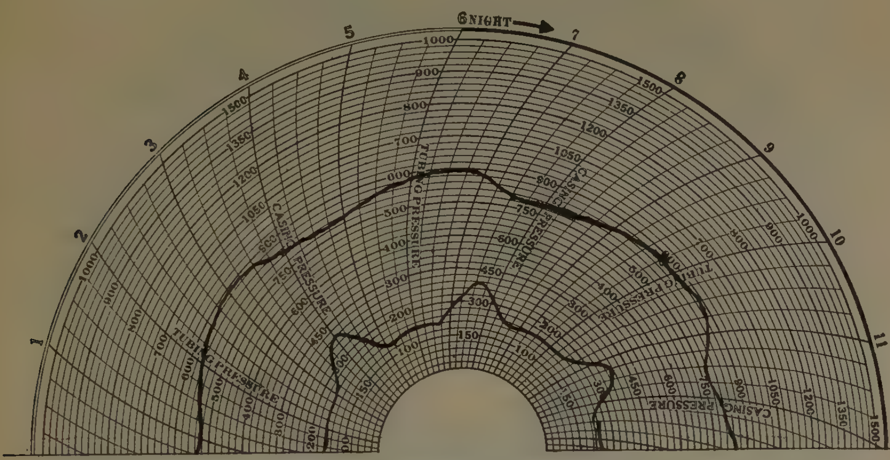

FIG. 2.—ILLUSTRATING CONDITIONS CAUSED BY USING TUBING TOO SMALL FOR OUTPUT OF WELL.
Pressure builds up in casing and escapes in heads through tubing.

WELLS WITH SUITABLE TUBING VELOCITIES, BUT OUT OF TIME

The third type of well, and the ones needing the most careful handling, were the wells which were characterized as being "out of time." These wells had sufficient gas to give them a good flowing velocity, but, for a reason not immediately apparent at the time, would surge or head. The cause was finally traced to the effect of the large volume chamber between the tubing and the casing. Something in the well or at the tubinghead would get this volume of gas to pulsating widely. This produced a surging effect in the flow string, and when it became wide enough, got the well to heading badly. It was found that by pulling the tubing and running a packer, thereby eliminating the volume chamber, the wells went back to steady flow. However, this was considerable trouble, and an easier method was sought.

Once the column of gas got surging back of the tubing, the condition kept getting worse and worse, eventually causing the well to head, and perhaps to cease flowing altogether. During the head, gas escaped from behind the tubing into the flow string in large quantities, thereby reducing

the pressure behind the tubing to such an extent that gas went into the annular space instead of into the flow string, causing a dead period until the pressure had built up sufficiently behind the tubing to kick over another head (Fig. 3). The older and smaller the well, the greater the time required to fill the annular space, and the greater the time between heads.

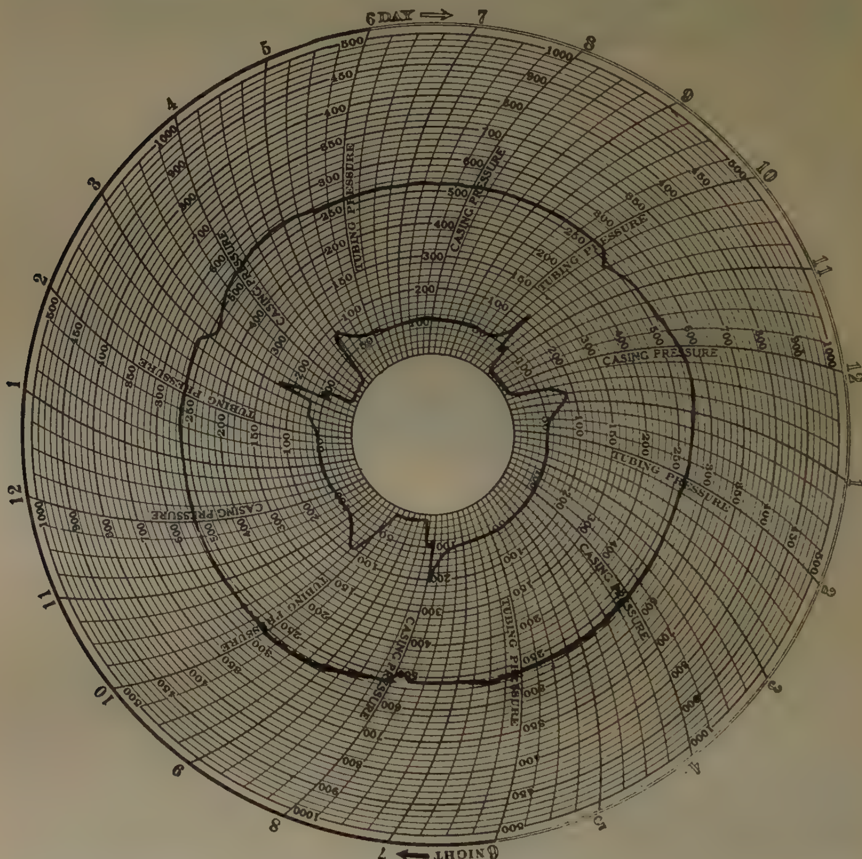

Fig. 3.—Well getting "out of time" by gas occasionally getting into tubing from behind tubing.

It was reasoned that if the gas could be kept from escaping from behind the tubing on surges or heads, the wells would steady down again. Bottom-hole chokes were suggested, but were discarded because of the difficulty of adjustment. Adjustable chokes for the Christmas tree were found to be successful. When a well got "out of time," as indicated by a surging or heading condition while there was still ample gas for velocity for steady flow, an adjustable choke was placed in the Christmas tree. A production foreman then waited for a head, as indicated by the

tubinghead pressure rising and the casinghead pressure falling. He then choked the well until the casinghead pressure ceased to decline, but not enough to kill the well. This prevented the escape of gas from the annular space, and reduced the well to steady flow, though at a low rate, due to the choke. The choke was then opened very gradually, care being taken not to allow the gas to escape from behind the tubing,

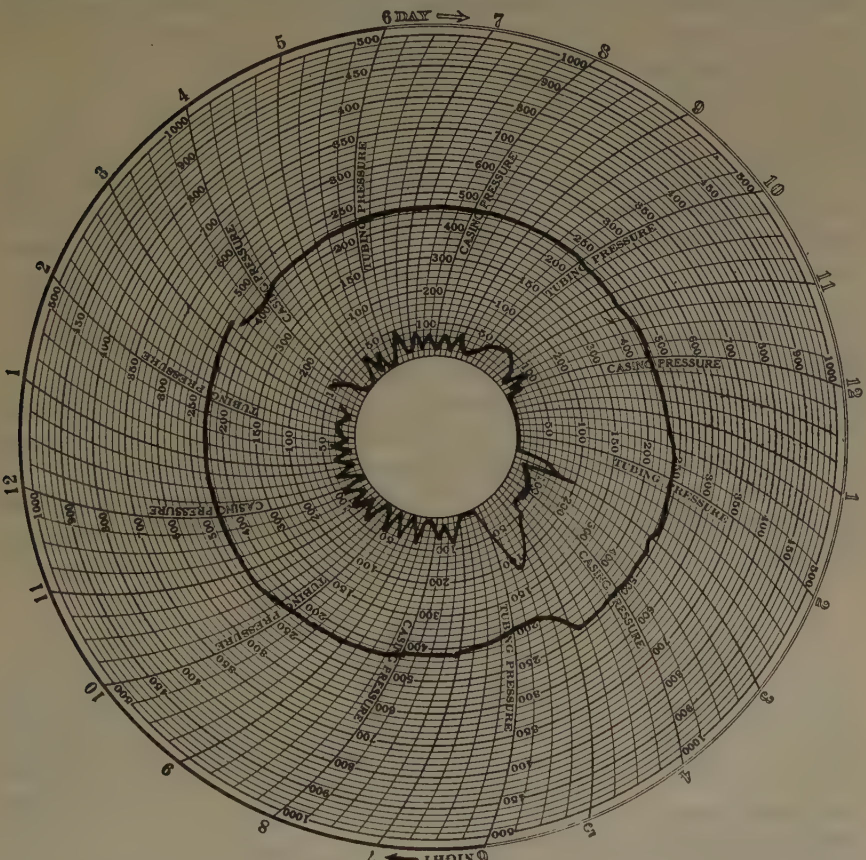

Fig. 4.—Well heading due to insufficient volume of oil and gas to give required minimum velocity.

until the well was at its former production rate on steady flow, the surging and heading with its pulling in of sand having been eliminated.

Wells with Insufficient Velocity in the Flow String

The final type of flowing well was the familiar one where the production of oil and gas had decreased to such an extent that the total volume of oil and gas was insufficient to give the necessary minimum velocity. (Fig. 4). Such wells could be brought back to steady flow by the intro-

duction of extra gas or air, or by running a smaller size flow string as described on page 227. This type of well is too well known through gas-lift literature to need further description. By careful handling of wells in the Maracaibo district along the lines outlined in this paper as regards velocity of flow, and by conservation of gas through proper back-pressure, it was possible to keep wells from arriving at this stage until they had reached a production of approximately 150 bbl., thereby going direct from this stage of steady flow to the pumping stage without the intervention of the gas-air-lift stage.

Conclusions

Based upon the above classification of flowing wells, the writer would put forth the following conclusions. They apply to wells flowing by gas and not by hydrostatic pressure. Wells in such fields as the Seminole, where there is neither hydrostatic pressure nor sufficient gas to lift the oil, are also excluded.

1. That flow velocity furnishes a convenient and accurate index for estimating the flowing potentialities of a well.

2. That unless a certain minimum velocity, depending upon viscosity and other factors, is attained, a well will not flow even though it has a volume of gas available mechanically sufficient to lift the fluid.

3. That by attention to flow velocities and conservation of gas, the natural flowing life of wells can be prolonged over to the pumping stage without an intervening air-gas-lift period.

DISCUSSION

C. V. Millikan,* Tulsa, Okla.—Mr. Donohue has used the pressure recorded at the casinghead as the bottom-hole pressure. Care must be used in assuming that the bottom-hole pressure is the same as the casinghead pressure, as a column of fluid may extend above the bottom of the tubing, between the tubing and casing, causing the pressure at the casinghead to be less than the pressure at the bottom of the tubing. An example existed in a well in the Seminole field, which had 8⅝-in. casing, 6⅝-in. casing and 2-in. tubing without packer. The 6⅝-in. was perforated at the bottom of the 8⅝-in. casing at approximately 4,000 ft., and the tubing extended a few feet below the perforations. While flowing through the tubing against 12 lb. pressure, the pressure between the tubing and the 6⅝-in. casing was 60 lb., and between the 6⅝ and 8⅝-in. casing was 450 lb. The pressure between the tubing and the 6⅝-in. casing could be released without changing the pressure between 6⅝, and 8⅝-in. or changing the rate of production.

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Mid-Continent Practices in Handling Flowing Wells

By Reid W. Bond,* D. L. Trax,† C. D. Watson‡ and Morgan Walker,§
Tulsa, Okla.

(Tulsa Meeting, October, 1929)

Common practice in the Mid-Continent until recently was to prolong the natural flow of oil wells as long as possible by agitation, and then swab for a short period until the well was put on the pump. Comparatively recently the gas-lift has superseded the swabbing and agitating period and in some cases encroached on the natural flowing life, particularly where it was evident that the potential oil capacity of the well was greater than the gas supply, or lifting medium.

The majority of wells are finished with either 6¼, 6⅝ or 8¼-in. casing and connected to a separator through a flow line which is usually 6⅝ in. The flow line is generally designed to eliminate sharp turns and has reduced the gas-oil ratio and therefore increased the efficiency in a good many instances. Until recently all wells were allowed to flow without restriction against the possible trap pressure until it was deemed advisable to put them on gas-lift. This resulted in a fairly efficient flow during the early life of the well if the well was rather large but was usually inefficient in small wells and in the later flowing life of large wells, on account of the large area in the casing and therefore excessive slippage.

Recently, considerable effort has been made to increase the efficiency of small flowing wells by running tubing to eliminate as much slippage as possible. With large wells there is a considerable trend toward back-pressuring, or beaning to find out whether it is possible to reduce the gas-oil ratios and increase the flowing life.

The greater number of fields that have been back-pressured have been produced in that manner through necessity, either to restrict production for proration purposes or, in fields producing by hydraulic pressure, to reduce water encroaching. The recent Cromwell sand development in Little River is an example where both back-pressuring by means of high-pressure traps and beans and flowing through tubing were used to conserve gas, reduce the high gas-oil ratio and prolong the flowing life. It

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† Chief Engineer, Gypsy Oil Co.
‡ Chief Engineer, Carter Oil Co.
§ Production Engineer, Amerada Petroleum Corpn.

was notable in this case that the best results were obtained by holding back-pressure by means of high-pressure traps. Flowing through the tubing did not greatly reduce the gas-oil ratio in most instances, even though the volume of oil was small, which can probably be accounted for by the large gas volume and excessive friction in the small tubing. There have been several instances of producing wells through tubing with the bean at the bottom, which the authors believe have been fairly successful.

While both back-pressure and tubing methods have been employed in California for some time, there has been little interest in this work in the Mid-Continent until recently, probably due primarily to the difference in the producing horizons. The thick, soft, high-pressure sands in California were better adapted for these measures than the thin, hard and comparatively low-pressure Mid-Continent sands. In fact, in California it is often necessary to produce through a bean in order to avoid sanding up.

Gas-lift Period

The wells usually are put on the gas-lift as soon as it is possible to run tubing into them. Sometimes the wells are allowed to flow naturally until they are heading or dead, depending on gas-oil ratios, sand characteristics, etc., but for competitive reasons most wells have been put on the lift as soon as possible in hope of increasing the production. Often this has been accomplished and resulted in increased production as well as increased efficiency, as more oil was produced with practically the same amount of formation gas. Usually the wells are cased with 6⅝-in. casing as an oil string and tubed with 2½-in. tubing. The flow is up through the annular space between the tubing and the casing and the gas is supplied through the tubing. Some wells use 2-in. tubing, and a few have been finished with 8¼-in. casing and tubed with 3-in. tubing. Recently a number of companies have installed combination hook-ups, so that the wells can be flowed up through either the casing or the tubing. This calls for larger tubing, generally 3 or 4 in. and the flush production is produced through the annular space between the tubing and casing. When the well declines the flow is reversed and better flowing efficiency is usually obtained.

When gas-lift work was first started in the Mid-Continent field, everybody strove to obtain a steady flow. Within the last year or so the intermittent method has steadily gained favor, using either an electrical or a mechanical timing device to switch the discharge of an entire compressor station from well to well at intervals determined by experiment. There has been considerable saving in injected gas in most cases and in some instances an appreciable increase in production. Possibly the saving in

gas was due to the use of large volumes for short periods of time which resulted in increased velocity at the bottom of the hole, where slippage is the greatest, and therefore increased efficiency.

The average calculated velocity at the bottom of the hole, in cases of which we have record using straight flow, is about 9 ft. per second, which obviously is too low for the best efficiency. The accepted tubing and casing practice leaves such a large annular area at the bottom of the hole that it can be efficient only in very large wells. Theoretically the tapered flow string should give much better efficiencies than can be obtained in the accepted gas-lift practice, but for several practical

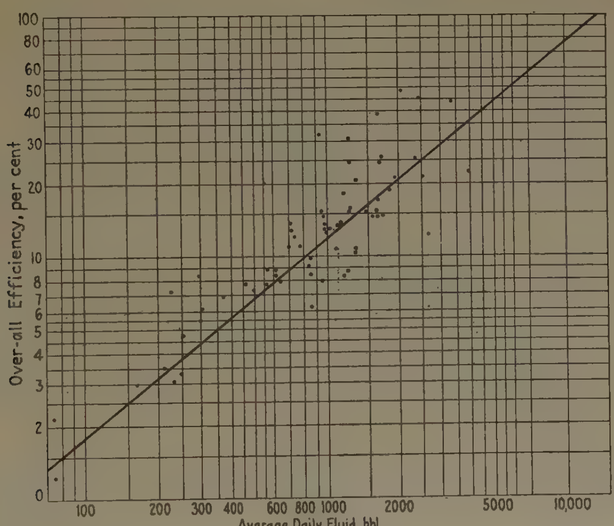

FIG. 1.—AVERAGE OF 21 SEMINOLE GAS-LIFT WELLS WITH 6⅝-IN. CASING AND 2½-IN. TUBING.

reasons it has proved more economical to disregard this method of obtaining efficiency. Scaling and corrosion in tapered strings has caused partial and total plugging of the string, the scale wedging in the swedged nipples and causing decreased production. The size of the tapered string is limited by the casing and in large wells more oil can be produced through the annular area than through the tapered tubing; even though the operation is less efficient, it is generally more profitable, particularly when the field is highly competitive. Also, where the decline is rapid the design and size of the tapered strings have to be changed frequently, which is not desirable in highly competitive fields.

Fig. 1 shows the over-all efficiency plotted against the production of numerous wells with 6⅝ in. casing and 2½ in. tubing on continuous

flow. The efficiency is a relative over-all efficiency calculated from the following formula:

$$\text{Efficiency} = \frac{\text{Free gas fluid ratio}}{\dfrac{0.072\,Lg}{\log_{10}\dfrac{P_1}{P_2}}}$$

L = tubing depth plus height of the trap
g = specific gravity of fluid
P_1 = absolute pressure at bottom = approximately the gage pressure at top plus 14.7 lb., plus weight of gas, minus friction (friction computed by Oliphant formula)
P_2 = absolute trap pressure.

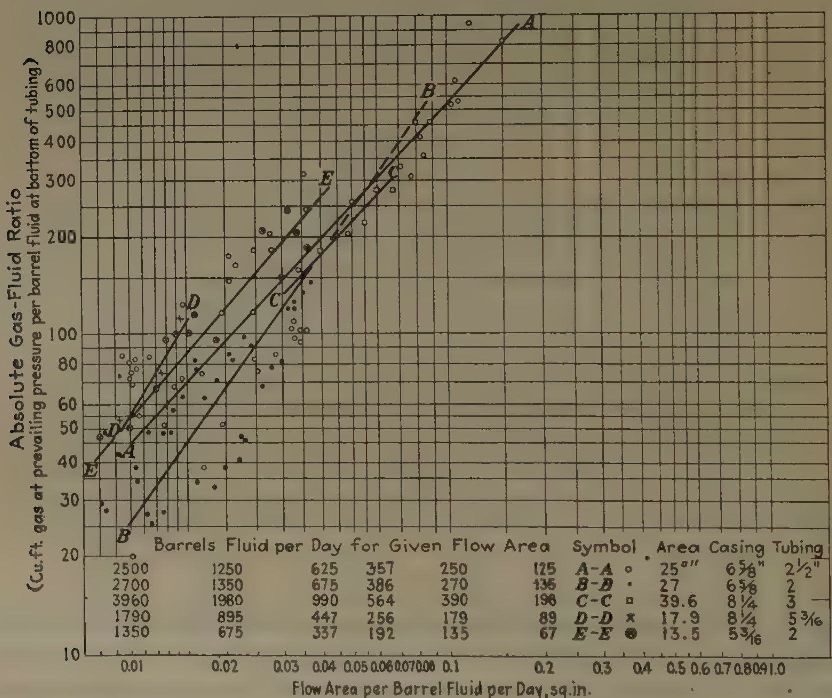

FIG. 2.—AVERAGE OF 50 SEMINOLE GAS-LIFT WELLS DURING VARIOUS PERIODS.

Efficiency curves were plotted for combinations other than the $6\frac{5}{8}$ and $2\frac{1}{2}$ in. and the same general trends were observed, but there was such wide divergence and irregularity due to variations in other factors that only general conclusions could be drawn. Most of the wells used in these computations produced little or no water.

Fig. 2 shows the absolute gas-oil ratio at the bottom of the tubing at the prevailing pressure plotted against the annular flow area in

square inches divided by the barrels of fluid per day. The data are composites of figures on a number of wells on straight flow through the annular space beyond the casing and tubing and include 6⅝ and 2 in.; 6⅝ and 2½ in.; 8 and 5³⁄₁₆ in.; 8 and 3 in. and 5³⁄₁₆ and 2-in. combinations. All of the wells were about 4200 ft. deep. The 6⅝ and 2-in. combination has a slightly higher average working pressure than the 6⅝ and 2½ in. and a slightly lower absolute gas-oil ratio, especially for the larger wells. For the smaller wells, say less than 400 bbl., the trend appears to be slightly in favor of the 6⅝ and 2½ in. Considering the average over the entire flowing life, for wells under consideration, the 2½-in. tubing seems to have

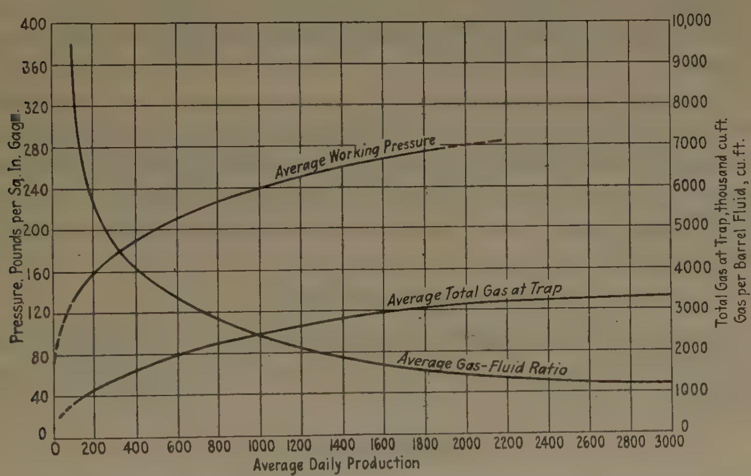

FIG. 3.—AVERAGE OF 30 SEMINOLE GAS-LIFT WELLS WITH 6⅝-IN. CASING AND 2-IN. TUBING.

a slightly higher gas-oil ratio than the 2-in. tubing. It is noted that for the 6⅝ and 2½-in. combination the average total volume of gas in thousands of cubic feet metered at the trap is approximated to be 10 times the working pressure. This is especially true for the larger wells.

Data were available on a considerably smaller number of wells having other sizes, and the average results could easily be changed by additional data. The data for the 5³⁄₁₆ and 2-in. combination in general showed a decrease in over-all efficiency and an increase in gross gas-oil ratio over the 6⅝ and 2 or 2½-in. combinations. Most of the wells cased with 5³⁄₁₆ in. happened to be larger wells and the happy medium between minimum slippage and minimum friction seems to have been passed, the increase in friction having more than balanced the decrease in slippage. The comparatively few cases of 8¼ and 3 in. seem to fall in line with about the same absolute gas-oil ratio; but due to reduced pressure drop through the 3 in., there appears to be a little higher over-all efficiency.

The 8¼ and 5³⁄₁₆-in. casing (flowing through 5³⁄₁₆-in.) appears to be justified only in special instances.

In all cases the velocity, in feet per second at the bottom of the well, for any given point on the curve is equal to

$$\frac{1}{600} \times \frac{\text{abs. gas fluid ratio}}{\text{sq. inches area per barrel of fluid}}.$$

A straight line at 45° through the points on this curve would indicate a constant velocity for all sizes of wells for a given flow area.

Fig. 3 shows the average working pressure, total gas, and gas-oil ratio, plotted against average daily production for approximately 100 wells in the Seminole area having 6⅝-in. casing, 2½-in. tubing with an average depth of 4250 ft. Here again a divergence of as much as 100 per cent. was found.

Due to the numerous variable factors involved and the unequal number of the various sizes of flow-string combinations compared, no definite conclusions should be drawn at this time, although the work to date shows definite trends which with additional data over a longer period of time should prove valuable in the study of natural flow and gas-lift operations.

Acknowledgments

The authors wish to express their appreciation of the able assistance of Mr. W. H. Collins and Mr. W. A. P. Fisher in preparing the data for this paper.

DISCUSSION

J. R. McWilliams,* Tulsa, Okla.—Our conclusions concerning Seminole flowing wells agree fairly well with those in this paper. However, we had one case that might appear contradictory. A well was completed with 8¼-in. casing on the Viola lime. Instead of running 2½ or 3-in. tubing for gas-lift purposes, we ran 5³⁄₁₆ in. casing and perforated it near the bottom. Gas was introduced into the annular space between the two strings of casing and the well produced through the 5³⁄₁₆ in. The well produced very satisfactorily, judging from the way it had swabbed and comparing it with offset wells equipped with 5³⁄₁₆-in. casing and 2-in. tubing.

When the well had declined to around 480 bbl., it was decided to try intermittent flow, and believing the annular space between the 8¼ and 5³⁄₁₆ in. would provide too large a reservoir detrimental to intermittent flow, we ran a string of 2 in. tubing in order to introduce the gas. The oil production dropped from 480 to 250 bbl. when the well flowed between the 5³⁄₁₆-in. casing and 2-in. tubing. We were unable to increase the oil production by changing the intermittent conditions. We also tried steady flow with like results although different volumes of gas were introduced. In the course of a few weeks, the tubing was pulled and the gas again introduced between the 8¼ in. and 5³⁄₁₆ in. with the result that production went back to 480 bbl. and we had some gages around 570 bbl. Another interesting fact was that the pressure on the 2 in. tubing under steady flowing conditions was 220 lb., while the pressure was 150 lb. when the gas was introduced between the 8¼ in. and 5³⁄₁₆ inch.

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The authors point out that in the Little River area they had better results holding back-pressure on the trap than they had with flow beans. Is this method preferred in general? I thought the way to hold back-pressure was with the trap.

E. H. Griswold,* Ponca City, Okla.—One reason why lower gas-oil ratios apparently are obtained by holding pressure on the trap, rather than with a choke is an error in gas measurements caused by increasing amounts of gas dissolved in the oil as the trap pressure is raised. The flow bean has another benefit over trap pressures in that it does not encourage a well to flow by heads, the difference being caused by the fact that the choke gives a restriction to flow but does not hold a back-pressure on the well during periods when the well would tend to head up. Another point is that of slippage in the surface flow line, which under high trap pressures may be sufficient to decrease the production of the well.

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* Petroleum Engineer, Continental Oil Co.

Chapter V. Increasing the Extraction of Oil

Repressuring in the Selover Zone at Seal Beach and the Effect of Proration*

By A. H. Bell † and E. W. Webb,‡ Los Angeles, Calif.

(Los Angeles Meeting, October, 1929)

Repressuring, or gas drive, was first tried in the Seal Beach oil field during the fall of 1927, and was carried on until the spring of 1928. This experiment in the Upper or Bixby zone was highly successful in proving the feasibility of compressing gas to high pressures and also showed great increases in production. The project was discontinued because there were not enough wells to protect the property lines. In the development of the second or Selover zone, many more wells were drilled and after 2½ years of production the gas was depleted so that all producing wells in the zone were either pumping or on gas-lift. Edgewater encroachment and the deepening of wells on neighboring properties to a third zone practically isolated the lease, so that during the spring of 1929 it was considered feasible to repressure the Selover zone on the Bixby lease of the Continental Oil Co. (Marland).

As shown on Fig. 1, the main Seal Beach structure is an elongated dome with a northwest-southeast trend, and the north flank is cut by a fault nearly parallel to the axis of the structure. Bixby well No. 24 was chosen for the injection well on account of its location, as it is backed up by the fault and is surrounded by wells that protect the property lines. The results of the test made in the Bixby zone indicated that an injection well on the flanks of the structure would drive oil quickly to up-structure wells but would have a tendency to cause by-passing, while the drive to down-structure wells would be slower but more evenly distributed. Preferably the injection well would have been located on top of the dome but property divisions made this inadvisable. Well 24 had been completed in November, 1928, but on account of gas depletion the well failed to flow naturally. On gas-lift the well had an initial production of 1000 bbl. of oil with 30 per cent. emulsion. This well is 4825 ft. deep, penetrating 200 ft. of oil-bearing formation. At the time the well was prepared

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† Production Engineer, Continental Oil Co.

‡ Production Foreman, Continental Oil Co.

for gas injection, the static fluid level was measured and found to be 1350 ft. from the surface. By calculating the weight of the column of fluid in the hole, an idea was gained as to the approximate pressure necessary to force gas into the sand. A packer was set at 4445 ft. on 2½-in. upset tubing, with 150 ft. of tubing below the packer, and the space between the casing and tubing was filled with water and closed in. Injection of gas was started Feb. 10, 1929, at a pressure of 1160 lb. per square inch.

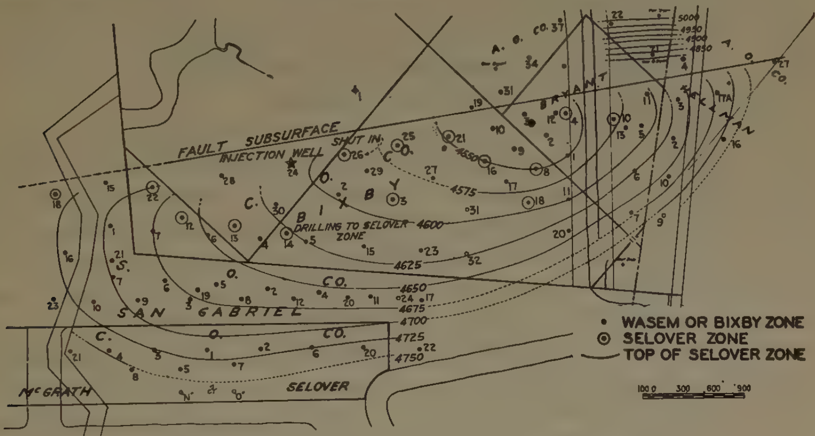

Fig. 1.—Main portion of Seal Beach oil field.

Method of Gas Injection

The repressuring work is carried on in connection with gas-lift operations, so that the volume of gas injected varies, being the surplus after gas-lift requirements are satisfied. The compressor installation is a central plant with nine 170-hp. Cooper direct-connected gas engine compressors. The gas is compressed in two stages from 27 to 550 lb. per sq. in. for the gas-lift operations, and the surplus is further compressed in one stage to 1200 to 1400 lb., by one of the engines, which is fitted with cylinders of 4½-in. dia. The volume injected daily has varied from 1,000,000 to 2,500,000 cubic feet.

The difficulties in operating this high-pressure unit have been surprisingly few. The chief source of trouble was from piston rings, which lasted only 9 days. The short life was due to condensates, which cut the lubricating oil, and by increasing the scrubber facilities the average life of the rings was lengthened to 29 days. Even this was not altogether satisfactory and a set of piston rings made of softer material was tried; namely, Kelly metal. At the end of five months of continuous operation these rings were still in good condition.

The chief field difficulty was from freezing in the line. The hot gases carried through a 2-in. line about 1400 ft. to the well. No appreciable friction loss was encountered but a slight expansion of the gas through

the check valve into the tubing caused freezing of condensates in the line at this point, which caused shutdowns and dangerous work in thawing out the line under the high pressure. This was remedied by placing electric heating units with thermostatic controls around each side of the check valve, insulating the heating units and pipe with asbestos covering.

Increase in Production

The injection pressure continued constant at 1160 lb. for several weeks, although the surrounding well pressures started to rise within a few days. The injection pressures later rose gradually to 1250 lb., indicating retention of some of the gas in the sand.

Fig. 2 shows graphically the results reduced to the average per well for seven wells. Two wells, Bixby 12 and 13, down structure from the injection well, had been operated by gas-lift for about 20 months, but after injection both wells started to flow intermittently without gas-lift, and Bixby 25, up structure, also started to flow without gas-lift. Two wells that were completed after repressuring began, and which produced large quantities of oil on account of the repressuring, are not included in the averages on Fig. 2. The first of these wells, Bixby 26, adjacent to the injection well up structure, was completed March 27, 1929, and came in flowing at the rate of 1000 bbl. daily with 870,000 cu. ft. of gas. The gas output doubled in July and the well was beaned back to 750 lb. tubing pressure, but still produced 1,800,000 cu. ft. of gas; it was shut in on July 19, 1929. After this well was shut in, the next well up structure, No. 25, increased its flow 220 bbl. daily. Bixby 14 was completed as a skimmer in the upper portion of the Selover sand on Aug. 29, 1929, although adjacent well Bixby 5 had been abandoned in the same zone several months before because of water encroachment. Bixby 14 came on production flowing naturally and made over 2000 bbl. of clean oil daily with 1,800,000 cu. ft. of gas. The performance of this well could only be credited to the pressures built up from the repressuring project.

The average production per well showed a definite downward trend prior to Feb. 10, 1929, and a sharp upward turn after repressuring started. The formation gas increased and casing pressures rose. During March, repressuring was stopped for 5 days and the sharp drop in production to the original trend is noticeable. During the latter part of March, the increases in casing pressures made it necessary to raise the tubing in some of the wells in order to handle them on gas-lift with the pressures available.

In April, the wells were all beaned back sharply on account of proration orders. The oil production dropped under the beaning in greater proportion than the formation gas, and the circulated gas-oil ratios increased sharply. The partial restriction of the formation gas caused a building up of sand pressures, and although the beans were not enlarged

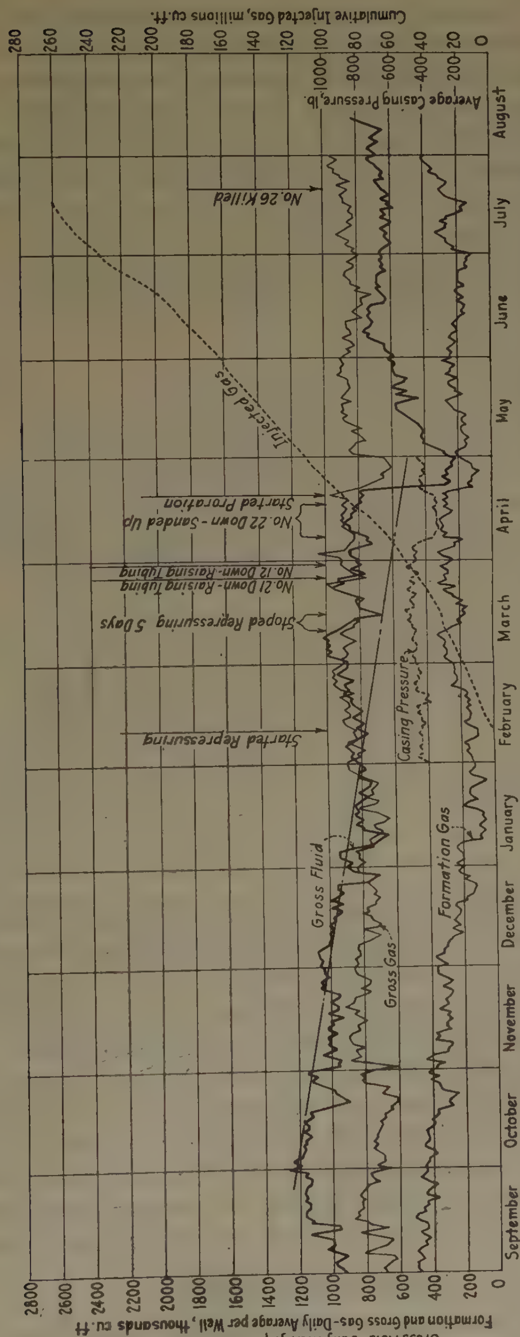

FIG. 2.—DAILY AVERAGE GROSS PRODUCTION PER WELL, BIXBY WELLS 3-12-13-16-21-22-25, SHOWING EFFECTS OF REPRESSURING.

the production gradually increased until it approached its former figure. The wells continued to produce gross fluid at a high rate, but water encroachment, which had started in some of the wells only a few weeks before repressuring started, caused decline in net oil production.

Fig. 3 shows the average net clean oil per well plotted against the cumulative production per well. This curve shows a definite trend until June, 1928, when the completion of several wells reduced the flow

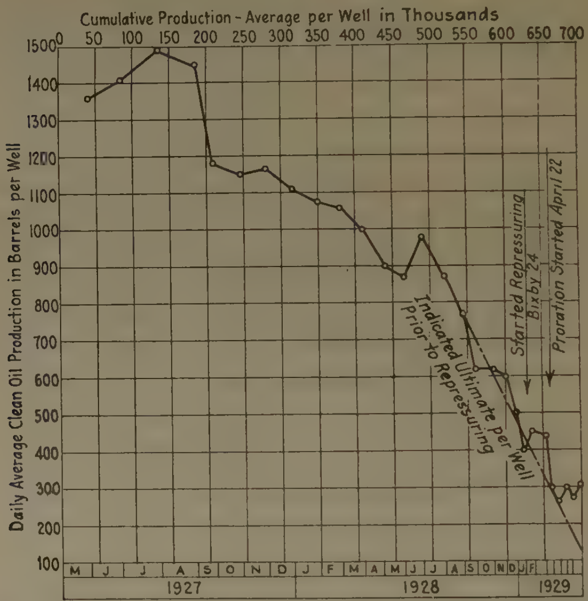

FIG. 3.—CUMULATIVE PRODUCTION, BIXBY WELLS, SELOVER SAND.

of the earlier wells and a more normal decline set in. This decline had a definite downward trend, which was interrupted in February with only a partial month of repressuring. The rapid drop of April, due to proration, was again reversed in June, July and August. During September these wells were all shut in but repressuring was continued.

A comparison of gasoline content of the gas produced from the various wells indicated that most of the wells showed increases between January and July, in spite of the fact that the proportion of formation gas to circulated gas was much higher in January, as shown on Fig. 2. There seems to be no explanation for the increase in gasoline content, unless it is due to agitation in the sand from the extraneous gas.

RESULTS OF PROJECT

The most notable result of this project has been the tendency of the gas to short-cut to wells up structure while wells down structure have had large production increases without increases in formation gas-oil ratios.

A study of the results on all of the wells indicates that the ideal location for an injection well would be the top of the dome so that the gas driving down on the top of the fluid in the reservoir would have less tendency to break through. Also, by supplying gas from the top to replace the oil taken out by flank wells, water encroachment could be practically eliminated if the input and output were properly regulated.

It is evident, from the results after beaning the wells when proration was put into effect, that in similar structures depleted wells can be made to flow again if the gas is injected in sufficient quantities and the flow from surrounding wells restricted to allow the sand pressures to be built up.

DISCUSSION

S. C. Herold,* Los Angeles, Calif.—We are familiar with the stratification diagram of fluids, gas on top, oil in the center and water below. We might expect, then, with any repressuring or driving with gas or air, that such gas or air should be applied at the higher contours of the structure to force the oil downward, thus avoiding an otherwise natural tendency for this gas or air to bypass the oil. It is interesting to note an actual verification of this principle in the Seal Beach properties as outlined by Mr. Bell.

In accordance with the same diagram, I have previously stated that in applying the water drive, as in the Bradford, Pennsylvania, area we should drive from the lower contours to force the oil upward. Undoubtedly the efficiency of the operations will be enhanced when we comply with nature's rule for the stratification of fluids. It is probable that the bypassing of the driving fluid cannot be avoided entirely in any case. We can hope only to minimize it.

What is the appearance of the rings taken from the cylinders when used under such high pressures as 1800 lb? Are they pitted or worn symmetrically? Is the wearing of the rings purely mechanical or at least in part chemical?

A. H. Bell.—Purely mechanical; just the case of complete elimination of all lubrication. The rings were worn very evenly. We did not at first expect anything so quickly. After the first failures we were prepared; we would take them out and look at them every few days and change them at suitable intervals. After we put this other metal in the packing rings we looked at them at the end of a week and at the end of a month, and after that we stopped looking at them. We tried to get the Compressor Manufacturers to adopt them. Probably they will after a while. It certainly is a means of stopping slippage on high-pressure gas.

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* Petroleum Geologist.

Repressuring in Depleted Oil Zones

By C. M. Nickerson,* Los Angeles, Calif.

(Los Angeles Meeting, October, 1929)

It is apparent that repressuring of the oil measures is becoming increasingly important to the oil industry, and is a matter that warrants the best efforts of the petroleum engineer charged with applying this method of operation to a producing property. Considerable attention has been directed to repressuring in various California oil fields, such as Dominguez and Seal Beach, which have served to sell the more progressive operator on this idea and also to keep him sold. The projects that have received most attention are in comparatively young fields where the fluid levels are high, the wells, perhaps, still flowing, where the wet gas production is of considerable volume, and where there is vital need of immediate conservation of gas, which otherwise would be blown to the air.

The new State of California Gas Law, which prohibits the waste of gas, has served to interest the oil industry in means of conserving the gas that is now being blown to the air because of lack of markets. This vitally affects the operator in the older, well-depleted oil fields of the state, because in many cases he has a limited market for gas, on account of the flush production from the more active oil fields. While the waste of gas is relatively small in these older fields, such as the Midway-Sunset area, it now attains considerable importance, since under the new State Gas Law it must be put to some beneficial use.

Repressuring in the older fields of California has not received the attention of the petroleum engineers that is warranted by the present situation. This paper was prepared with the view of presenting the salient features connected with repressuring in the well-depleted oil measures of the older fields, and to show what results have already been obtained in these fields by injecting the unmarketable gas into the sands, particularly in the Midway-Sunset field in the San Joaquin Valley of California. Other projects in the older fields of the state offer some supporting data in this connection, such as the Shields Canyon and the Brea Canyon fields.

Gas Storage and Repressuring

On account of the lack of market for a large portion of the dry gas produced in certain of the older, well-depleted oil fields of California, the

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operators are forced to blow this gas to the air or to put the gas underground for future use. At first this was considered as merely a gas-storage proposition in the oil zone, as differentiated from storage in a dry zone. As the volume put underground increased, certain fluctuations in the production of the surrounding wells were noted. Further observations and study led the operators to believe that the gas-storage proposition could be more correctly termed a repressuring program. During the last two years these projects have come to be looked on as a repressuring program, although an appreciable proportion of the gas pumped underground could still be considered as stored there for future use.

The lack of necessary records of gas production, gasoline content, etc., for individual wells in these older fields has seriously handicapped the petroleum engineer in studies of the actual results obtained from repressuring where the adjoining wells were on production. However, several important facts have been developed which may be useful in future repressuring programs in certain fields in California, where conditions may be comparable to those existing in the Midway-Sunset oil field and in the Elk Hills field.

Subsurface Conditions, Depleted Fields

It may be well to set forth the subsurface conditions in a typical well-depleted oil field of California, in order to explain better the results obtained by repressuring these oil zones. The Buena Vista hills anticline is an integral portion of the more extensive Midway-Sunset monocline, located in the San Joaquin Valley. The oil measures vary in thickness from approximately 600 ft. on the top of the structure to less than 100 ft. on the northwest flank. On several of the leases, where injection is under way, the average thickness of the sands is 200 to 300 ft. The oil zone consists of alternating strata of pulverulent, poorly cemented oil sand, and sandy shales, interstratified in a predominantly shale body. The fluid levels in the field are comparatively low, usually less than 500 ft. above the top of the perforations in the oil string. The wells vary from 3000 to 4000 ft. in depth. The well-depleted character of the oil measures in the Buena Vista hills is shown by a production, to date, of 32,000 bbl. per acre, which represents approximately 75 per cent. of the estimated ultimate yield. Considering the low fluid levels and the present production per well of 20 to 80 bbl. per day, it is safe to assume that the upper portion of the oil zone is well depleted of its oil content, and that numerous open spaces may be found which would offer little resistance to the passage of gas from one location to another. The production of wet gas and natural gasoline is still of considerable volume, since the field is not in the last stages of depletion.

Injection Pressures and Volumes

The pressure under which the gas was injected in Buena Vista hills was less than 200 lb. in most cases, and at least 300,000 cu. ft. could be injected daily into an individual well. The source of the dry gas was the gasoline compressor and absorption plants on the lease, which normally discharge the gas to the sales line at 300-lb. pressure. On certain of the leases where only 80-lb. pressure was available, additional compressors, or high-compression cylinders, were installed to obtain the required pressure. Figs. 1 and 2 show the average daily volumes and injection pressures for typical repressuring programs in the well-depleted field, the adjoining wells being on production. These curves show that the injection pressure remained practically constant for a widely varying volume of gas. However, if sufficient volume were injected the pressure required would be increased somewhat. These figures are for leases that are not appreciably affected by encroaching edge water. Owing to the experimental character of the various programs studied by the writer, complete data were not always available; an attempt was made to determine the ratio between injection pressure and volume but was unsuccessful. As these projects are continued, further information may be obtained which will permit the determination of the maximum volume of gas that may be forced into the oil zone at a given pressure. None of the operators has found it necessary to inject all of the available gas into one well in order to determine the injection pressure changes, since there are sufficient wells available for injection purposes on the several leases.

The best use possible was made of existing facilities on the lease. No elaborate plants or hook-ups have been installed for repressuring purposes. The dry gas from the discharge meter of the compressor plants was piped through available lines to the key well, and often these lines were not of the most economical size nor in the place desired. Pressure loss in the gas lines and leaks were taken for granted. The gas was available at a given pressure at the plant and whatever could be put underground was so much less to be blown to the air. More efficient installations will be found in the future as repressuring of these depleted fields becomes the common practice.

Choice of Key Wells

The wells selected for injection purposes have not always been in the best mechanical condition nor at the best structural location. The key well should generally be selected as low down on the structure as the boundaries of the lease will permit. The location should be as far removed from the borders of the lease as is feasible in order to confine the benefits of the repressuring to the one lease, unless cooperation is obtained from the neighboring operator. In the older fields, it has often been found advisable to utilize for injection purposes a well that was

about to be abandoned on account of bad mechanical condition. If the well will not produce oil, but will receive gas into the oil zone, it becomes a source of profit instead of an added expense, since the removal from production of another well is rendered unnecessary.

The key well should be cleaned out to bottom to facilitate injection and the connections made to the casinghead in order to pump the gas into the oil zone. Sometimes it was necessary to utilize the tubing in the well to gas-lift the oil from the hole until the fluid level had been lowered sufficiently to allow the gas to enter the formation under the available pressure. During the cleaning out of the well the fluid might be lowered to the desired level. The comparatively low fluid levels in the more depleted fields offer but little difficulty to the passage of the gas into the formation.

Results Obtained

Fig. 1 shows a typical injection project, giving the injection pressure of between 160 and 175 lb., a daily average injection volume ranging from 200,000 cu. ft. to 280,000 cu. ft. for the individual well, and the average daily production of oil from an offsetting well. Within a month

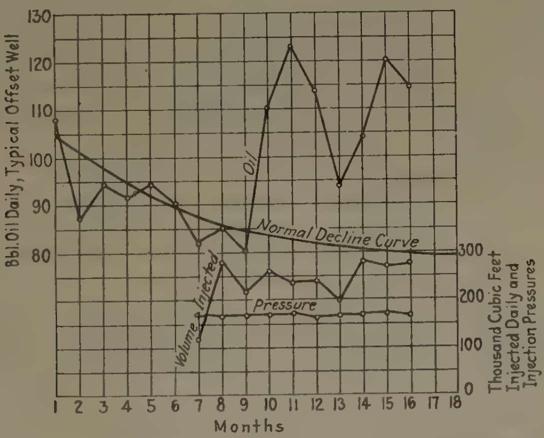

Fig. 1.—Effects of injection on oil production.

or two after injection was started beneficial results were noted on the daily oil production of wells in the vicinity of the key well. The oil production of the typical well was greatly increased, and as the injected volume of gas was decreased each month, the oil production declined also. With an increase of 30 per cent. in the injected volume of gas the daily average barrels of oil increased almost to the former peak, as shown on Fig. 1. Not all of the wells were so favorably affected by the injection program but no well in the vicinity of the key well appears to have been adversely affected. There is every reason to believe that the decline curve of the well illustrated in Fig. 1 will meet the former estimated

decline curve many months in the future, the difference between the estimated curve and the actual curve following injection representing the increased volumes of oil obtained by repressuring on the lease.

Somewhat similar results are shown on Fig. 2, which pictures conditions on a lease in the Buena Vista hills. The injection pressure remained constant at 160 lb., while during the period of a year the volume of gas injected increased from 125,000 cu. ft. daily average per month to 225,000 cu. ft. and then decreased to 130,000 cu. ft. daily. Data from the offsetting wells, as illustrated by the curves on this figure, show that the decline curve for daily barrels of oil turned upward within a few months after injection was undertaken, and had not reached its peak after a period of 9 months. The ultimate recovery of oil from the off-

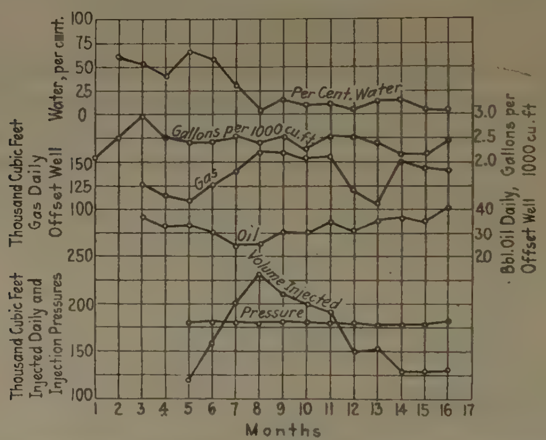

FIG. 2.—PRODUCTION DATA OF TYPICAL WELLS OFFSETTING INJECTION WELL.

setting well has been greatly increased by repressuring. Shortly after the program was initiated on this lease, the gas production of certain offsetting wells increased about 50 per cent., showing that the injected gas was reaching the well, probably by-passing the oil somewhat. Little attempt was made to control the migration of the gas by use of back-pressure on the offsetting wells, although this is feasible in most cases. The gasoline content of the wet gas from the offsetting wells showed a rather steady decline in gallons per thousand cubic feet (Fig. 2). This may be interpreted as indicating that the dry gas was reaching the well and diluting the wet gas ordinarily produced, without picking up any appreciable amount of the lighter hydrocarbons in the crude oil. However, the large increase in production of wet gas more than offset the drop in the gallons per thousand cubic feet, and increased production of natural-gas gasoline from the well. Another beneficial result, which may be attributed to repressuring, is the decrease in some cases in the percentage

of water produced by the offsetting wells, leading to lowered lifting costs and larger ultimate recoveries. Fig. 2 illustrates a drop in the volume of water from more than 50 per cent. to about 10 per cent. of the fluid produced. The oil curve turned upward at the time the water percentage curve reached 10 per cent., indicating, perhaps, that the water formerly produced was holding back or entrapping certain volumes of oil. The lease that gave the production curves of Fig. 2 is not within the edge-water line but does produce considerable water let into the oil zone by faulty shut-offs, etc. The decrease in the water cut may be attributed to flattening of the water cone, or actual prevention of infiltration of the water into the oil zone, by the pressure of the injected gas.

Notes on Shields Canyon

In the Shields Canyon field, 200,000 cu. ft. per day per well has been injected into the shallow zone at approximately 230-lb. pressure. The offsetting wells were producing between 3 and 5 bbl. of oil per day. After 18 months of intermittent repressuring the oil production from the majority of the wells had been materially increased, while the key wells after being returned to production had a daily yield greater than when they were taken off production for injection purposes.

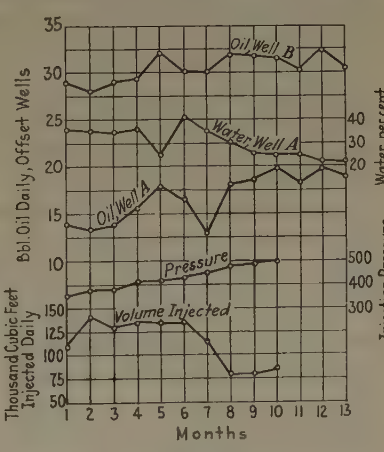

Fig. 3.—Injection data for edge-water area.

Injection in Edge-water Area

If a lease is located within the edge-water line on the borders of a field and repressuring is started, a somewhat different set of conditions is met. Bottom water may have encroached to a point higher on the structure than the injection well. Fluid levels may be considerably higher than on a lease that is well up on the structure. The percentage of water produced from such a well is usually rather high. Injection has been undertaken on a small lease on the edge of the Elk Hills oil field, where these conditions obtain. The curves for this lease are illustrated on Fig. 3. Here the injection pressure required was considerably higher than in the well-depleted oil zones where edge water was not a major consideration. An initial pressure of 360 lb. was required, which increased steadily over a period of 10 months to 500 lb. The volume of gas injected was approximately 135,000 cu. ft. per day for this time. For the last few months the volume injected was decreased to 60,000 cu. ft.

per day, resulting in a very slight flattening of the pressure curve. The daily average oil production of certain of the offsetting wells showed a considerable increase over a period of a year. The percentage of water produced by one well decreased from 40 to 20 per cent., with varying decreased water cuts on several of the remaining wells in the vicinity.

Conclusions

On the basis of past experience in repressuring in the depleted oil zones of the older fields of California, it may be safely concluded that the injection of gas into such a zone will result in considerable benefit to the operator, such as increased oil recovery, a slower rate of decline of the well, and an increased volume of natural-gas gasoline. A few years ago it was generally held that repressuring could not be undertaken on any except comparatively large leases of two or three sections in area. Recent developments have shown that this production method will be successful on leases as small as a quarter section. As much benefit cannot be obtained on so small a lease as would be possible if a larger area were under the control of a single operator, because of the tendency of the effects of the increased formation pressure to travel across the property line.

Confining of the effects of the repressuring program to the area of the lease may be obtained by maintaining high fluid levels on the line wells and using a center well for injection purposes, at the same time producing the intermediate wells at a rapid rate under a relatively low back-pressure. This will result in some by-passing of the gas, which would probably occur anyway in the partially drained oil zone, in the obtaining of the increased oil recovery due to the gas-drive effect from intermediate wells, and in some decrease in the water production of the lease.

Another method of obtaining full benefits from a repressuring program on a comparatively small lease involves holding back-pressure on the wells adjacent to the key wells, thus forcing the gas to travel a greater distance away from the injection well, and producing the line wells at maximum capacity under a comparatively low back-pressure. By this means the gas injected is forced to do the maximum amount of work, considering the limits of the lease; the increased oil recovery is obtained from the line wells; the circulated gas will have a higher gasoline content as it travels further through the oil zone, and in general a large area of the lease is repressured with only a small chance of the oil being forced off the lease to the wells of a competing neighbor.

In the event of whole-hearted cooperation by neighboring operators even more beneficial results may be obtained by a repressuring program. If adjoining operators can agree, the key wells may be located as direct offsets across the section line, with equal volumes of gas injected into each

well, thus permitting full benefits of the program to be obtained by each operator, since he does not feel that he is merely forcing a portion of his own oil into the neighbor's wells. The distance that the gas may be forced to travel by this method will be nearly doubled. The producing wells adjoining the injection well can have their back-pressure increased without diminishing the oil production to any material extent, the gas forced to the next location, and the operation repeated, until the effects are noted on wells near the opposite section line. When this occurs the line wells should be operated at full capacity in order to make sure that the oil stays on the proper lease. The recirculated gas will have a higher gasoline content, caused by the increased distance it is forced to travel, thus tending to reduce the extraction cost of the gasoline.

The reduction of the water production of the lease will tend to lower the lifting costs, and will normally be accompanied by an increase in oil production. On many of the older leases in California a large portion of the water produced with the oil may not be edge water, but water let into the formation by faulty drilling, leaking shut-offs, bad casing in suspended producers, etc. Some of the results obtained on various leases indicated that the injection of gas tends to hold back this type of water and to permit certain volumes of oil formerly trapped by the infiltrating water to be produced, thus increasing the ultimate recovery of oil. While unit operation of a structure may be the ideal method of obtaining the maximum volume of oil from each property, the lack of 100 per cent. agreement should not prevent all attempts to utilize the excess dry gas.

The market demands for dry gas in California fluctuate several hundred per cent. over the year, while the daily and weekly demands for gas show marked changes. The supply of dry gas from the gasoline compressor plants is constant, and cannot be regulated according to the market demand. An operator faced with a limited market for gas should be able to inject the excess over sales requirements into key wells on even a comparatively small lease, varying the injected volume on a daily, weekly and seasonal schedule. By this method he can sell all the gas that is needed for domestic and industrial uses, and inject the excess into the oil zone in varying amounts; the effects will continue to some extent after injection has ceased temporarily. On several of the projects in the state, injection was stopped and beneficial effects were noted on wells in the vicinity for several months afterwards. Over the week-ends there is a decreased demand for gas for use as fuel in the industrial centers, while during the summer months the domestic demand shrinks to a comparatively small figure. There appears to be no good reason why intermittent injection of gas could not be adapted to the fluctuation of the demand. Some operators believe that a constant volume of gas should be injected into a well each day and each month, but the writer

sees no real reason for this procedure, since intermittent injection of gas has proved successful in several instances.

Some companies use the dry-gas zone for storing gas that cannot be used at the moment, withdrawing the gas for use at the first opportunity. Storage of gas in a dry-gas zone is not the subject of this paper and need not be considered here, but is a parallel procedure for injection in varying amounts into the oil zone, where it may be considered as repressuring or as gas storage. A well so used for injection into the oil zone should not be considered as a gas-storage well, since the reproducing of the gas from the same well with adjoining wells on production would nullify certain of the benefits to be expected by allowing the gas to travel to adjoining wells and be produced there as wet gas.

If a lease is entirely shut in and no wells are on production, surprisingly large volumes of gas may be injected into the oil zone and stored there. The casinghead pressures on wells in the vicinity should be recorded frequently in order to determine the extent of the migration of the gas and to prevent a blowout. Ultimately, a high pressure will be built up over the area of the lease. If any wells outside of the shut-in limits are producing, they should be carefully gaged and any undue changes in production analyzed. This may permit of a modification of the back-pressures on certain of the shut-in wells so as to minimize the possibility of driving oil off the lease. The benefits of the gas thus stored will be obtained when the lease is returned to production, in increased production from the several wells.

Summary

1. The repressuring of a depleted lease producing as little as 3 to 5 bbl. of oil per well per day is feasible.

2. Gas may be injected into a lease as small as a quarter section and the benefits therefrom confined to the property.

3. The volumes and injection pressures necessary in the depleted field are within reach of the usual compressor capacities found in the natural-gas gasoline plants on the lease.

4. Intermittent injection of gas will eliminate the necessity of blowing the excess gas to the air, and will bring the supply more in line with the widely fluctuating market demands, thus permitting compliance with the new California Gas Law.

5. The benefits of repressuring a well-depleted lease include: An increase in the oil production of the offsetting wells; a decrease in the water production, resulting in lessened lifting costs; an increase in the volume of wet gas produced by the wells; and an increase in the total gallons of gasoline obtained from the wet gas, although the gasoline content may have dropped.

6. When the injection well is returned to production the barrels of oil per day will ordinarily be found to have increased over that prior to the injection of the gas.

7. The use of increased back-pressures will offer some control to the direction of migration of the gas.

8. The injected gas should be forced to travel the longest distance possible underground in order to obtain the maximum benefit from the injection pressure, and from the increased gasoline content.

9. The value of the increased gasoline recovery in most cases will be more than equal to the cost of the injection.

10. The ultimate production of oil from the lease will be increased to a material extent.

Acknowledgments

In the preparation of this paper, the writer acknowledges the kind assistance and helpful cooperation of the various engineers engaged in repressuring programs, especially A. H. Bell, V. H. Wilhelm and G. I. McBride.

DISCUSSION

W. W. Scott,* Houston, Texas.—The Humble Oil & Refining Co. is repressuring in the Powell field, Texas. Repressuring operations have been going on since March 31, 1926. Most of you are familiar with the fault type of structure and the water drive there.

We are injecting about 2,000,000 ft. of air and have been doing so for about a year on account of lack of gas. We are getting an increase in the production of oil and gasoline recovery, and think we have retarded the movement of water up the dip as injection wells are placed down the dip. In some instances, wells that have been abandoned as producers have been used for this purpose.

S. C. Herold,† Los Angeles, Calif.—It is interesting to note that Mr. Nickerson makes a distinction between injection wells and storage wells. It is advisable to distinguish between the operations of injection and storage. Mechanically they are somewhat similar, in so far as they are accomplished by compression pumps, but their purposes are distinct. The beneficial results obtained by injection are undeniable. It certainly increases the rate of production from adjoining wells. If we are to store gas in the productive horizons of this state the gas will creep up the structure and form there what we may term a large bubble. It will not be a bubble to the complete exclusion of oil, but one wherein most oil is displaced by gas. The pool of oil will be thus maintained in its spread over the structure; edge wells will be maintained in oil as a consequence.

The formation of such a bubble will take place in our processes of injection in California. Then against Mr. Nickerson's fifth statement in the summary, I believe that we must list the disadvantages resulting from such a bubble on the crest of the structure.

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* Chief Petroleum Engineer, Humble Oil & Refining Co.

† Petroleum Geologist.

I would take issue with Mr. Nickerson and others who advocate the increase of ultimate production from a field at large in California by repressuring. And with these fields we can include those of the Gulf Coast region, Mexico, and in fact all fields wherein production is in either hydraulic or volumetric control. I say the ultimate production from the field at large is not affected. For the individual properties it certainly is affected. The man who gets there first and gets the oil out most rapidly gets the most oil, particularly if his property is on the flank of the structure, less probably if his property is on the crest of the structure.

In the Mid-Continent and Eastern regions, wherein production is in capillary control the ultimate production from the field at large is increased by repressuring. Here repressuring would be more accurately described as a forced drive by gas.

As to the use of increased back-pressures in item 7, I agree that it will offer some control over the direction of migration of gas, but it seems to be certain that if we place back-pressure on our wells we benefit our neighbors, if we have them.

A. H. Bell* Los Angeles, Calif.—I take exception to the statement that there is no increase in production in California pools. We had a good example at Seal Beach of an increase in production of between 25,000 and 30,000 bbl. of oil that was trapped between two well locations. The well that we injected had previously produced as much as 5000 bbl. of clear water daily. A well on a neighboring property, which was producing about 80 per cent. water and a couple of hundred barrels of oil, jumped up to over 2000 bbl. of oil. That is oil that would ultimately have been lost. We had already abandoned our well and the neighboring well would have been abandoned within a few months. This trapped oil production can certainly be classed as increase in production for the field. We did not get it, but it was produced in the field. An enormous amount could have been produced if we had gone through the whole field, repressuring each well before abandonment. In other words, the oil is driven out of the trap in the upper part of the sand. It could not escape into the wells either up or down structure. The gas drive would naturally hang to the top and force the oil out.

S. C. Herold.—In a case of that sort I fear I must concede your point. I am assuming, when I make my statement, that there is at least one well on top of the structure that can take the last of the oil that is to come to us. If there is no such well, of course we can increase the ultimate production by forcing the oil from the crest to a well conveniently located on the flank.

Possibly I am inclined to give less credit to the existence of local traps than most people are. Perhaps I should ask if by a trap you mean a condition in the sand where a porous section is completely surrounded by a relatively tight section.

A. H. Bell.—I mean space between the well locations and structural curves. The water encroaches more or less in a straight line and leaves a layer of oil between the water line and the overlying shale, where the oil would not have any avenue of escape.

S. C. Herold.—Inasmuch as no anticlinal structure is geometrically perfect, I suppose we may find minor undulations in the productive formations between wells. These may indeed serve as traps, but what is in them? Necessarily gas. Gas will tend to hang to the roof of the formation, will it not?

A. H. Bell.—Yes, but the gas is depleted.

S. C. Herold.—By injection you are maintaining the presence of gas. I believe that our tests on gas-oil ratios when back-pressures are altered verify the fact that

* Continental Oil Co.

these traps take more gas on the increase of the back-pressure, and give up an excess of gas on the release of this back-pressure.

C. M. Nickerson.—My paper was written about a field that is about 15 miles long and 4 or 5 miles wide. Mr. Bell's paper[1] concerns a field that is possibly 1 or 2 miles long. There is a great difference in viewpoint in repressuring these two different types of fields. In the Seal Beach field it is possible for one company to have repressured right down to the edge-water line. In the larger fields of the state this is almost impossible, since the companies do not own such large blocks of acreage that the lease covers an area from the crest to the edge-water line of the structure. If the lease is one square mile in area, an operator must consider how to repressure for his own benefit, and not with the idea of unit operation of the structure. In this case a well will be chosen ordinarily down dip, because the effect will travel up dip; *i. e.*, will be noted mainly on his own property. If a well is selected on the up-dip property line for injection purposes, the entire effect would probably be noted on the section above and few benefits obtained by the section below the contour line on which the injection well is located. It was with the idea of repressuring a small lease, assuming little cooperation possible with the neighboring lessees, that I stated that the choice of the key well should be made as low down on the structure as the shape of the lease permits.

In any study of repressuring problems I am impressed with the existence of two schools of thought, one considering the question from a theoretical viewpoint that the entire structure is owned by one operator and that repressuring can be undertaken with the unit operation idea, and the other considering the problem from a practical viewpoint that a lease does not cover the entire structure, that large quantities of gas are available for injection, and that injection is desirable regardless of any lack of cooperation with neighboring operations. While unit operation of a structure may be the ideal solution of the problem, these projects are few in number and have advanced but little beyond the theoretical stage. The practical consideration of present lease boundaries, position on the structure, attitude of offsetting operators, etc., has led to repressuring programs that have confined the larger portion of the benefits of injection to the lease in question. Such a practical solution of injection on various leases has considerably more appeal to the board of directors and stockholders of an oil company than has a theoretical plan of unit operation with its attendant difficulties of cooperation. At some future date the unit operation of a structure may be the common practice, but at the present time, with large quantities of gas being blown to the air in California, comparatively small leases can be successfully repressured with the aid of present available knowledge, leaving any difficulties of cooperation, proration of oil, etc., for later consideration when unit operation is adopted.

[1] See page 240.

Recent Developments in Flooding Practice in the Bradford and Richburg Oil Fields*

By Charles R. Fettke,† Pittsburgh, Pa.

(New York Meeting, February, 1930)

Abstract

The Bradford and Richburg oil fields are the only pools where artificially conducted water drives on an extensive scale have been economically successful. Field practice has progressed from the original accidental or intentional circle flood, through the line flood development plan, to the intensive complete development plan, which is the most recent and generally considered to be the most successful. Of the intensive development plan the five-spot arrangement of wells is the one that has been used most extensively. A further development associated with the latter method is the application of additional hydraulic pressure to that of the hydrostatic head of the column of water in the intake well. In conjunction with this method is the practice of delayed drilling of the oil wells until the water from the intake wells has entered even the less permeable portions of the sand and developed a "bank" of oil at which time all oil wells are drilled as nearly simultaneously as possible. The five-spot pressure flood with delayed drilling gives more rapid return on investment than any other method. The seven-spot and nine-spot patterns are rarely used. No chemicals, such as sodium carbonate and other so-called flooding agents, are being added to the water at present since the field tests carried on in 1926 gave no positive results. All air and gas drives have been discontinued.

* This paper and discussion are available at the office of the Institute as *Technical Publication* No. 328.

† Professor of Geology and Mineralogy, Carnegie Institute of Technology.

Modern Practice in Water-flooding of Oil Sands in the Bradford and Allegany Fields

By Paul D. Torrey, Bradford, Pa.

(New York Meeting, February, 1930)

The water-flooding of oil sands has been widely practiced for many years in the Bradford and Allegany fields. Its effect upon the production of these fields has been almost phenomenal. In 1907 their estimated production was 3500 bbl. per day; in December, 1929, the combined production is estimated at 33,000 bbl. per day, an increase of almost 1000 per cent. in 22 years. This increase in production is directly attributable to the successful application of water-flooding, which has transformed the fields that were rapidly approaching abandonment into one of the most actively operated regions associated with the petroleum industry, and has made them important factors in the production of Pennsylvania Grade crude oil.

The writer is indebted to many companies for information included in this paper. He is particularly grateful to the Sloan and Zook Co., the Petroleum Reclamation Co., George Bovaird, Jr., and the Associated Producers Co., of Bradford, Pa., who have generously made available much valuable data. Owing to the frequently competitive and confidential nature of property purchases, it has not always been possible to make specific reference to individual wells or properties; but wherever feasible, specific references have been made.

Economic Factors

The successful application of water-flooding for increasing the recovery of oil has been almost confined to the Bradford and Allegany fields. This has been due not only to legal restrictions in other fields and to very favorable sand conditions in the Bradford-Allegany region, but also to certain economic factors which are worthy of consideration.

There has been some alarm regarding the effects of the rapidly increasing production upon the oil market but the writer is inclined to believe that future development can be made sufficiently flexible to meet the demand for this grade of oil. There has been a decided tendency toward consolidation of properties by mergers and purchases and, in addition, many of the individual producers are content to take advantage of floods advancing on their holdings from adjoining properties without developing their own on an intensive scale. Cooperative drilling along

property lines is widely practiced and results not only in material economies in development but also in desirable production control.

Both the Bradford and Allegany fields are well defined and produce oil from sand bodies of remarkable continuity and homogeneous character. Drilling and operating costs are comparatively cheap and easily determinable and an accurate appraisal of development expense is therefore simple. The precision with which costs and profits can be predicted, combined with a reasonable certainty of return based upon a fairly uniform average oil price, has attracted considerable outside capital, which has done much to expedite development.

The Bradford and Allegany fields, therefore, possess particular advantages which would not be encountered in many other fields. There are good reasons for questioning the advisability of attempting to water-flood certain fields where development costs are much higher and oil prices lower, even if there is definite evidence that water-flooding would materially increase the recovery.

Development of Flooding Methods

Since the publication of a former paper by the author,[1] there have been rather radical changes in development technology. The successful application of the line flood did much to establish water-flooding as the only consistently profitable method of increasing oil recovery in these fields, but it also had a marked effect upon the price demanded for properties. As the efficiency of the line flood became more evident, there was a corresponding increase in the valuation of oil properties. The adoption of intensive flooding operations was the natural result of this condition. Such developments were at first more or less experimental but the results from the original attempts were so encouraging and the increased economy of operation so evident that this method has been almost universally adopted during the past two years.

Intensive development consists in completely drilling an area according to some definite geometric pattern. The five-spot flood, consisting of one oil well equidistant from four water-intake wells arranged in a rectangular pattern, is, in reality, nothing more than a series of line floods. Various other patterns have been used to a lesser extent; they will be more fully described in the paragraphs devoted to well spacing.

The advantages of an intensive development over the line flood or other less systematic methods of flooding are: concentration of development and operations in one area with a consequent reduction in capital and operating expenses; rapid depletion, which further reduces operating expenses and materially reduces interest charges; and a more efficient flooding of the sand with a consequent increase in recovery.

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[1] P. D. Torrey: Some Factors Influencing the Production of Oil by Flooding in the Bradford and Allegany Fields. A. I. M. E. *Tech. Pub.* 39 (1927).

Water Supply

During the early period of water-flooding development, water was introduced into the sand either by cutting or by pulling the ground-water string of casing. This method was considerably improved by an act of the Pennsylvania legislature requiring that all water-intake wells be tubed from the bottom of the lowest fresh-water-bearing stratum to the top of the Bradford sand. At the time this law was passed, it was regarded by many operators as an unnecessary burden, for it was intended to protect other possible sands above the Bradford, but it proved to be a blessing in disguise, for the accumulation of cavings and other sediment on top of the sand was partly prevented. However, there is much evidence to indicate that many wells were plugged by sediment and by ferric hydroxide that passed down from the water-bearing horizons through the open couplings in the tubing to collect on and over the sand. It is hard to estimate how many water-intake wells were being effectively plugged while the operators were wondering why the anticipated results from their floods had failed to materialize.

In addition to the possibility of unknowingly plugging off the sand by uncontrolled water-floods, many floods have been actually starved, owing to a lack of adequate supplies of ground water. This is especially evident on properties located on hills where there are appreciable deviations in the level of the water table owing to seasonal variations in rainfall. The effect of the amount of rainfall on oil production is frequently very striking and in periods of drought it is known in certain instances to have decreased 50 per cent.

The intensive development of properties has in several instances been seriously hindered by a lack of water. In certain parts of Bradford field, where the area of watershed is limited, the situation has become so acute that supplementary supplies have been obtained from other sources. When it is considered that a modern five-spot flood frequently requires more water in a year than the total annual rainfall over the area drilled, it will be appreciated how essential it is to provide for an adequate water supply.

The ground water derived from the bed rock, in the Bradford field, ordinarily requires treating before it is suitable for flooding purposes. It occurs in more or less ferruginous beds and carries in solution appreciable amounts of ferrous carbonate, which is readily oxidized to ferric hydroxide when the water is exposed to the air. Several instances can be cited where ferric hydroxide, with suspended matter, has effectively plugged the sand, therefore it is becoming a rather general practice to agitate the water with air before it is flowed to the water pumping plant, and to run it through a rapid sand filter, using alum as a coagulant. This procedure removes all iron compounds and has been remarkably successful in eliminating much of the previous trouble.

Certain waters in the bed rock in the Bradford field possess marked corrosive properties, and it is questionable whether ordinary steel tubing and line pipe will be worth salvaging after the depletion of a property on which such waters occur. In fact, it is possible that much steel pipe will have to be replaced by corrosion-resisting alloy steels or that the pH of the water will have to be increased by chemical treatment.

Operation of Properties

There has been little change in actual operating technology in the Bradford-Allegany area since the publication of papers by Umpleby[2] and by Newby, Torrey, Fettke and Panyity.[3] The most notable

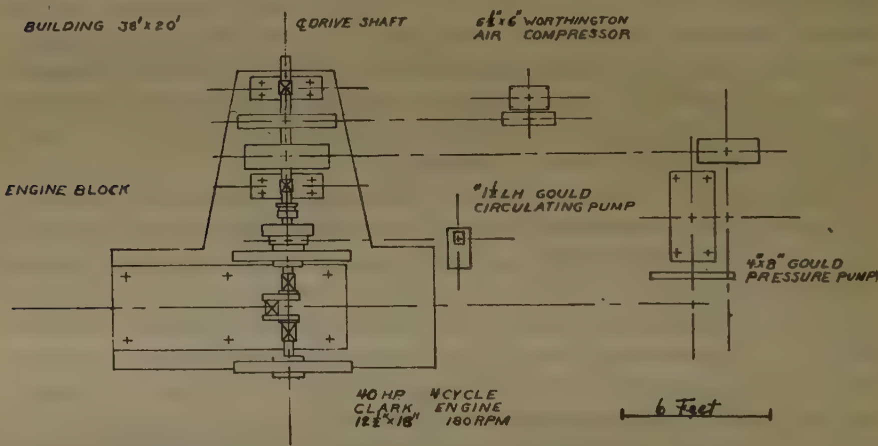

Fig. 1.—Arrangement of modern water pumping unit. After Petroleum Reclamation Co.

improvements are central water pumping plants and the extensive use of the diamond drill and cable tool core barrel for taking cores of the sand.

The use of central water plants, to supply the water-intake wells instead of depending on the subsurface water-bearing formations, was first applied to increase the pressure on tight sands. Their use, has, however, become more general, for they insure a continuous and uniform flow of water to each water-intake well. It is possible to meter the water going into every well, therefore, a much better control of flooding action is possible. In addition, it is possible to detect any plugging action from the record of the meters and to filter or otherwise treat the water if such procedure is necessary.

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[2] J. B. Umpleby: Increasing the Extraction of Oil by Water Flooding. Petroleum Development and Technology in 1925, A. I. M. E., 122.

[3] J. B. Newby, P. D. Torrey, C. R. Fettke and L. S. Panyity: Bradford Oil Field, McKean County, Pennsylvania and Cattaraugus County, New York. Structure of Typical American Oil Fields, **2**, 407–442, Amer. Assn. of Petr. Geol., 1929.

The value of the central water pumping plants has been clearly proved and few intensive developments are operated without them.

The coring of the oil sand to determine its character has become general. Both the diamond drill and cable-tool core barrel are being used. Each of these methods possesses certain advantages and in comparing them it should be appreciated that, in so far as the Bradford and Allegany fields are concerned, complete cores are of far greater importance than time or expense, especially when the investment of large sums of money is dependent on the results of the core analyses.

The diamond-drill cores that the writer has examined have been most complete and present an excellent record of the beds cored for lithologic studies. In some of the newer models the core is protected by an inner barrel, which has materially helped to prevent water circulation around the core. The high water pressure required for diamond drilling washes considerable oil from the sand, and since there is unquestionably some drainage of oil during the time required to pull the tools, samples taken for saturation tests may give inaccurate results.

The cable-tool core barrel possesses a considerable advantage in that the core is not subject to high water pressure and that samples of sand for saturation tests can be obtained easily in about 10 min. after they have been cut from the sand body. The actual coring of the sand can be done ordinarily as rapidly as drilling with the customary tools although, of course, more time is required when the tools are out of the hole to change bits, etc. The sands of both the Bradford and Allegany fields are almost uniformly thin-bedded, so most cable-tool cores are broken into small biscuits, which represent the thickness of the actual beds of sand. A Baker cable-tool core barrel, when operated by an experienced and competent driller, will take as complete a core of Bradford sand as any diamond drill on the market. In the Baker core barrel the core is as well protected, after it has been cut from the sand, as in the improved models of diamond drills; for the upper part of the inner core tube is equipped with a water valve which allows the water to escape as the core is pushed up into the tube.

The comparatively low cost and simplicity of the cable-tool core barrel has appealed to many oil producers, but its greatest advantage lies in the flexibility of its operation and the fact that samples for saturation tests can be obtained that more nearly approached actual conditions in the reservoir than those obtained by any other method.

Intensive water-flooding rapidly depletes the supply of gas on a property, so that there have been several replacements of gas engines by Diesels. More Diesel installations may be expected in the future, for the supply of gas is limited and purchased gas is much more expensive than fuel oil. Diesel electric plants may prove to be the most economical source of power.

Well Spacing

Probably the most important factor in determining the ultimate results from a water-flooding operation is the selection of a well-spacing pattern designed to conform best with the characteristics of the sand body underlying the property. There are many factors that determine the ideal spacing pattern for a property or area. Some of these—geometric pattern, sand porosity, saturation and total oil content of sand, water pressure and the element of time—are discussed in the following paragraphs.

Geometric Patterns

The well spacings used in line floods and circle floods have been adequately described and analyzed by Stephenson and Grettum.[4] The first pattern applied in intensive development was rectangular (the five-spot) with an oil well in the center of a square formed by four water-intake wells. This pattern is, in reality, nothing more than a series of line floods and it was, therefore, the natural change from the system of flooding most widely in use prior to the more general application of intensive development. Its use has been almost universal, owing to the ease with which it is fitted into property boundaries and the manner in which the distance between wells can be varied to conform to changing conditions in the sand body.

A triangular pattern has been used on a few properties. In this system an oil well is located in the center of an equilateral triangle formed by three water-intake wells. It is claimed by the operators using this pattern that it will add materially to the effectiveness of the flood, but comparative data are not available and it is somewhat questionable whether the possible increase in recovery will be sufficient to warrant the additional development expense required by this pattern. The triangular pattern alone is difficult to fit into property lines but frequently it may be applied to advantage in connection with a rectangular pattern in properties of irregular dimensions.

Some consideration has been given by various operators to the use of a hexagonal pattern. The hexagon possesses some distinct merits, for it is the polygon with the largest number of sides that will fit into a continuous pattern. A hexagonal arrangement of water-intake wells will undoubtedly increase the efficiency of a flood, for the oil well will be more effectively surrounded by water and the dangers of trapping oil between the intake wells will be diminished. The reduction in development cost by the use of a hexagonal pattern will be considerable except in the offset wells along the property lines and even here the saving in development

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[4] E. A. Stephenson and I. G. Grettum: Valuation of Flood Oil Properties. A. I. M. E. *Tech. Pub.* 323 (1930). For abstract see page 277.

expense probably will equal the value of the oil flooded on to adjoining properties.

Porosity of Sand

One of the most important factors determining the most desirable spacing for a property is the rapidity with which water will penetrate through the sand from the water-intake well to the oil well. The rate of travel of water through the sand is dependent upon the permeability, or capacity for penetration, of the sand; upon the water pressure, and upon the distance between the water-intake well and the oil well. The permeability of a sand depends upon the porosity and the degree of interconnection of pore spaces, the size and shape of the pore spaces, and to a lesser extent upon the type of cementing material and the oil saturation.

The size and shape of pore spaces are determined by the size and shape of the sand grains and by the amount of cementing material between the grains. The average size of grains of the Bradford sand is exceptionally uniform in comparison with the grain size of other petroleum-bearing horizons of the Appalachian fields and, although there are certain areas in the Bradford field in which the size of the sand grains is somewhat variable, it can be stated that, in general, the variations in the porosity of the Bradford sand are dependent upon the amount and type of cementing material present.

The cementing material of the Bradford sand is both argillaceous and siliceous. In the northern part of the field, argillaceous cementing material predominates. In the central part of the field there is considerably more silica present in the cement and in the southern part the cementing material is more purely siliceous, part of which seems to be of secondary origin.

The exact relationship between the porosity of the Bradford sand and its permeability is not a settled question. The writer believes that in so far as the Bradford and Richburg sands are concerned pieces of sand possessing the same dimensions and the same porosity and grain size will have approximately the same permeability under pressures corresponding to the pressures used in water-flooding. Evidence in favor of this theory has been found from laboratory experiments and from actual field experience.

The performance of comparable permeability tests in the laboratory is not always easy. It is frequently difficult to get samples of sufficient size and uniformity of texture, owing to the thin-bedded character of the sand, and it is sometimes rather hard to cut and grind the sand sample to a standard size. In order to make determinations which check with reasonable accuracy, the sand must be oil-free, for varying saturations of oil have a material effect upon the penetration of water at a fixed

pressure. For most permeability tests, the writer has ground the sand to a standard size of 2 by 2 by 1 in. and set it in a threaded collar, using ordinary type metal to hold the sample in position. This collar is fitted to a hydraulic pump equipped with suitable gages in order to maintain a constant pressure. Pressures varying from 100 to 5000 lb. per sq. in. have been used, but the most satisfactory results have been obtained using pressures from 500 to 1500 lb. It has been difficult to obtain satisfactory checks using low pressures and smaller pieces of sand and at excessively high pressures it is rather hard to maintain a constant pressure and to prevent leakage around the sample. In Fig. 2 the results of some of these tests are shown in graphic form; a reasonably close relationship between porosity and permeability is indicated. The sand samples used in these tests were obtained from the Schofield property

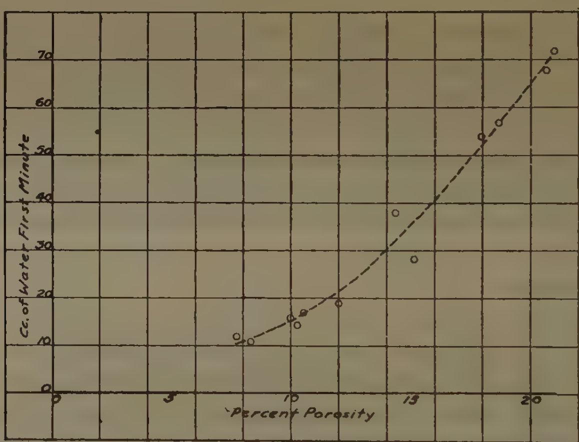

Fig. 2.—Relation between porosity and permeability of pieces of Bradford oil sand.

of Bovaird Oil Co.; the West Looker property of Petroleum Reclamation Co., and Seaward property of Bovaird and Hamlin. These properties are rather widely separated although the sand from all three possesses a uniform grain size and similar cementing material.

Where there is any considerable variation in grain size, it is impossible to obtain such a close correlation; and for this reason it has been appreciated for some time that the sand in the southern part of the Bradford field required, on the average, higher water pressures and closer well spacing than sand of similar porosity in the northern part.

The amount of experimental data available, although indicative of a fairly close correlation between porosity and permeability in the Bradford and Richburg sands, is, however, not sufficient to be absolutely conclusive; more reliable information can be obtained from a study of cores taken in areas that have been watered-out and abandoned. The writer

has recently had an opportunity to study several cores from what has been regarded as watered-out territory, and it can be definitely stated that the water moves most readily in the lenses of sand that possess the highest porosity. Examples of this condition can be cited from practically every part of the Bradford field. A very striking illustration is shown in Fig. 3. This core is from the southern part of the Bradford field, from an area that has been affected by water for over 10 years.

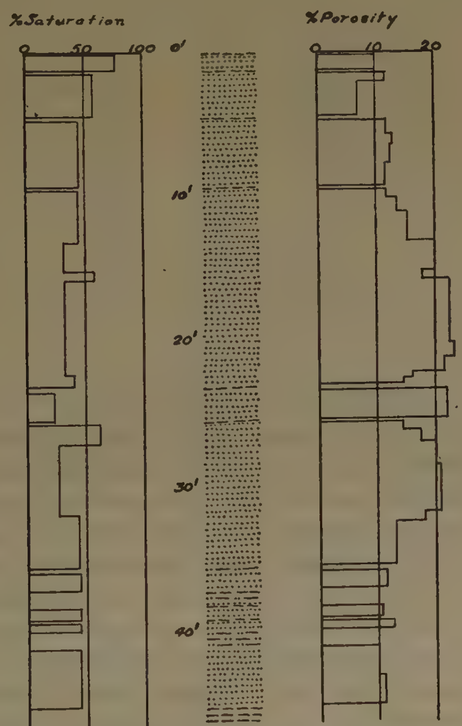

FIG. 3.—POROSITY AND SATURATION PROFILE OF CORE TAKEN FROM WATERED-OUT AREA IN SOUTHERN PART OF BRADFORD FIELD. OIL CONTENT, 19,709 BBL. PER ACRE.

The results of the analyses of saturation samples from this core are given in Table 1. These determinations show that the various lenses of this sand are in almost every stage of flooding action. Certain beds apparently have never been affected by water; in others the water has evidently removed all of the recoverable oil; and in still others the oil has been so concentrated by the water that the sand is probably completely saturated.

The results obtained from actual field experience can hardly be questioned and for this reason there seems to be no ground for not accepting the porosity of the Bradford or Richburg sands as a criterion of its

permeability, and as such it is one of the most important factors in determining the most desirable well spacing to apply on a property.

TABLE 1.—*Results of Saturation Tests on Samples of Sand from Core Illustrated in Fig.* 3

Sample No.	Porosity, Per Cent.	Oil Saturation, Per Cent.	Water Saturation, Per Cent.
1	9.82	75	nil
2	7.17	57	nil
4	12.46	45	50
6	15.22	24	54
7	20.27	22	78
8	17.71	57	nil
9	22.80	34	60
10	21.60	39	68
11	14.42	41	17
12	14.19	62	20
13	22.00	26	70
14	17.98	44	21
16	12.35	44	nil

Saturation and Oil Content of Sand

Much of the information previously published regarding the saturation and oil content of the Bradford sand has been misleading. The detailed analyses of hundreds of cores of the sand combined with studies of the relation of the amount of water introduced into the sand, with the total fluid and gas produced, indicate that the average oil saturation of the Bradford sand is about 55 per cent. Higher saturations are occasionally found in lenses that are apparently unconnected with the main sand body, and in areas where oil has been concentrated in the sand by flooding action, saturations approaching 100 per cent. are not uncommon. In general, the saturation of the sand is higher in structural lows than along anticlinal axes or in the Knapps Creek dome. In fact, the upper part of the sand, in the higher parts of the folds, is almost invariably a gas pay barren of oil, which presents a rather serious problem in flooding operations, since water will move much more readily through the depleted gas pays than through the saturated oil pay.

The results obtained from laboratory tests of oil saturation can be accepted as minimum figures for there is certainly some oil lost during the coring operation, but they can be readily checked by calculating the total volume of pore space in the sand and comparing it with the amount of water introduced into the sand and the volume of fluid and gas produced from the oil wells. In Table 2 such a comparison has been made, based on accurately kept data from several properties. It can be clearly seen that if the sand had possessed a saturation of from 80 to 85 per cent. it

would have been physically impossible to have put such volumes of water into the sand.

TABLE 2.—*Relation of Water Input to Oil Produced for Several Properties in Bradford and Allegany Fields*

Flood No.	Volume of Voids per Acre Calculated from Core Analyses, Bbl.	Volume of Oil per Acre Calculated from Core Analyses, Bbl.	Average Water Pressure at Top of Sand, Lb. per Sq. In.	Average Porosity of Sand, Per Cent.	Water Input per Acre, Bbl.	Oil Produced per Acre, Bbl.	Ratio Water Input to Oil Produced	Time Flood Has Been in Operation, Months
1	34,098	18,846	1,300	12.1	14,440	1,100	13.1	7
2	27,664	15,400	1,300	11.7	18,831	2,975	6.3	12
3	28,360	12,622	1,100	13.3	11,880	480	24.7	4
4	20,455	11,840	1,500	11.2	18,223	3,860	4.6	23
5	13,980	9,377	1,700	10.9	8,170	2,700	3.0	14

The determination of oil content is essential, not only because it has an important bearing upon the spacing that can be most advantageously employed but because it is, in most cases, an accurate criterion of property value.

Characteristics of the reservoir rock, such as the porosity and saturation of the sand, are reasonably constant but, since these conditions cannot be controlled in advance, it is necessary to apply a spacing pattern which past experience has shown may be expected to give the most favorable results. The factors of water pressure and the element of time are controllable by the operator and must be considered in selecting the most advantageous spacing for sands possessing certain specific characteristics.

The use of additional water pressure was first tried in the Allegany County fields, where it was found that the natural hydrostatic pressure was not sufficient to force adequate volumes of water into the sand, owing to its very low porosity. The first intensive floods in the Bradford field used close well spacings—from 200 to 250 ft. between water wells—but this spacing has been gradually increased until spacings of from 300 to 450 ft. between water wells are not uncommon. This increase in the dimensions of the spacing pattern has had a material effect in reducing development costs and has been made possible by the use of water pressures far above those considered feasible in the past.

The time required to deplete a five-spot or any other type of intensive flood can be predetermined with reasonable accuracy to meet the requirements of the operator, by varying the dimensions of the spacing pattern. A close spacing with normal water pressure will give rapid results, and is frequently used where it is desired to make a rapid return of the capital invested in land and development, or to build up a large production for the purpose of a sale. A wide spacing pattern possesses not only

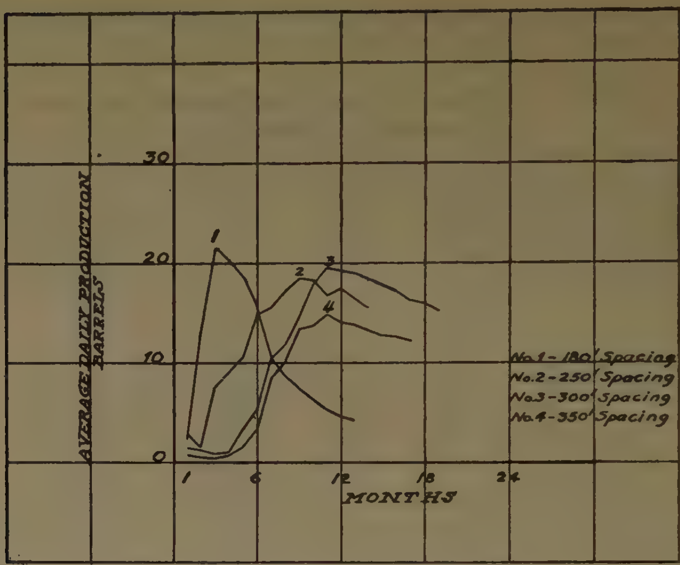

Fig. 4.—Oil production curves from five-spot wells of varying spacing patterns. Well spacings indicated represent distances between water-intake wells.

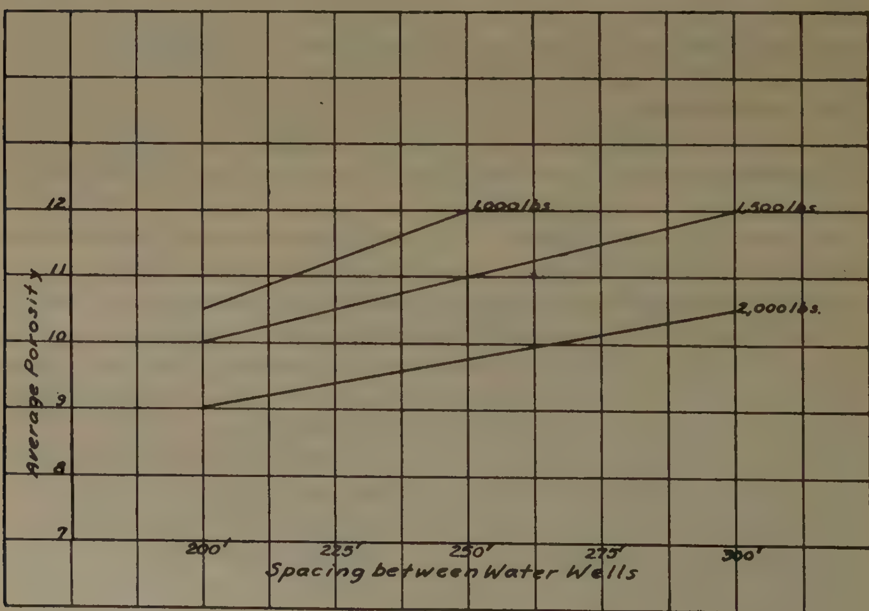

Fig. 5.—Desirable well spacings for certain porosities of sand and water pressures, applicable to properties in central part of Bradford field.

the material advantage of lowering the cost of development but the longer productive life of widely spaced floods permits a better opportunity for obtaining an average price for the oil produced. There has been a gradual but definite trend toward wider spacing patterns during the past year.

In Fig. 4 the production of a typical well from five-spot floods of different well spacing is given.

The description of the various factors upon which the selection of the most advantageous spacing pattern must be made leads to a definite analysis (Fig. 5) of these factors to determine the proper spacing for certain properties in the central part of the Bradford field. Analyses of this character cannot be reliable unless there is a close comparison between core studies and the results obtained from acutal field operations. In fact, core analyses are practically worthless unless they can be interpreted in the light of past operating experience. The most important feature in the construction of these graphs is in the calculation of an average porosity that is representative of the core. This is, of course, impossible where there are wide variations in porosity, and any recommendation that might be made for sand of this character should be based more upon the experience of the engineer and the actual operating problems of the operator than upon any predetermined formula. The data in Fig. 5 are based upon actual operating experience and represent the most up-to-date information on this subject, although future developments may, of course, present reasons for certain changes.

Recovery of Oil

Notwithstanding the certainty of developing oil production in the Bradford and Allegany fields, the recovery of oil by water-flooding is a most variable factor, depending both upon the method of operation and upon the oil content and character of the sand. There is unquestionable evidence that the recoveries obtained in the past from many properties are not a true indication of their worth, owing to a lack of adequate water supplies and to the fact that many intake wells were undoubtedly plugged by ferric hydroxide and suspended matter from the water. In addition, information obtained from cores taken in what are regarded as watered-out areas indicates how really inefficient many of the old floods have been, for, in some instances, not over 50 per cent. of the sand has been affected by the water and only about 25 per cent. of the sand has been effectively flooded. It may be reasonably expected that intensive development will materially increase recoveries obtained in the past, perhaps from 20 to 25 per cent., since the possibility of by-passing oil is reduced, and the hazard of inadequate water supply almost entirely removed.

It is impossible to apply a recovery factor that can be used with a fair degree of certainty for the large combined areas of the Bradford

and Allegany fields, owing to the factors previously described. By comparing recoveries, previously obtained from systematic developments and the present and anticipated recoveries from intensive floods, with the oil content of the sand determined from core analyses, the writer has found that efficient water floods, in sands possessing a porosity of average uniformity, are recovering approximately 40 per cent. of the oil contained in the sand. This figure has been checked sufficiently to warrant its use in estimating the oil recovery from undeveloped properties, and although indicated recoveries from core analyses cannot be offered as an absolute certainty they are, at least, a valuable index of comparative quality.

Increasing Recovery

The results of all of the recent improvements in the technology of water-flooding have had a material effect upon the efficiency of water-flooding operations, with a consequent increase in the recovery of oil. One of the most notable recent improvements in intensive development is "delayed drilling," which may have an important effect upon future developments in these fields.

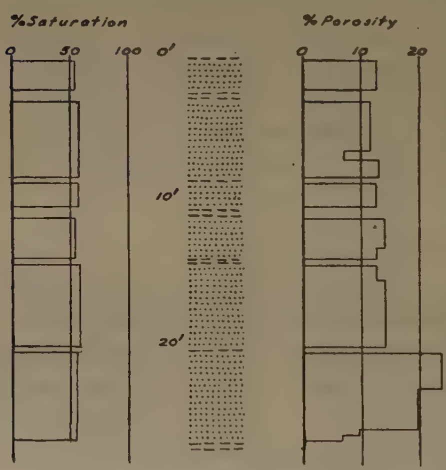

Fig. 6.—Porosity and saturation profile of core taken from property where delayed drilling was first tried. Oil content, 13,994 bbl. per acre.

Delayed drilling was first tried in an area in the Allegany field, where a previous five-spot flood had yielded unsatisfactory results. A core of the sand from this area is shown in Fig. 6, which conclusively proved why this flood was not giving the results that were anticipated. The water was moving through the highly permeable sand, of 20 to 25 per cent. porosity, without affecting the equally well saturated pay of lower porosity in the upper part of the sand.

The problem thus encountered was to try to develop a method for making the water move through the beds of low permeability. It seemed impractical to flood both types of sand separately so it was decided to drill an experimental five-spot flood south of the first five-spot, which would not be in any way affected by the first flood, and to delay the drilling of the oil wells for a period after the water had been let into the sand, which was to be determined from the analysis of another core.

The idea of delaying the drilling of the oil wells in a five-spot flood is based upon the fact that the sand body in the five-spot square possesses a definite and fixed capacity to hold fluid. As long as a constant pressure is maintained on the sand, each individual bed of the sand body will absorb water in proportion to its relative permeability. Experimental investigations have shown that the capacity for penetration is not directly proportional to the pressure; *i. e.*, as the pressure is increased there is not a constant and proportional increase in water input. In a sand such as the one in which delayed drilling was first tried, if the pressure is increased to the point where the sand of lower porosity will be flooded

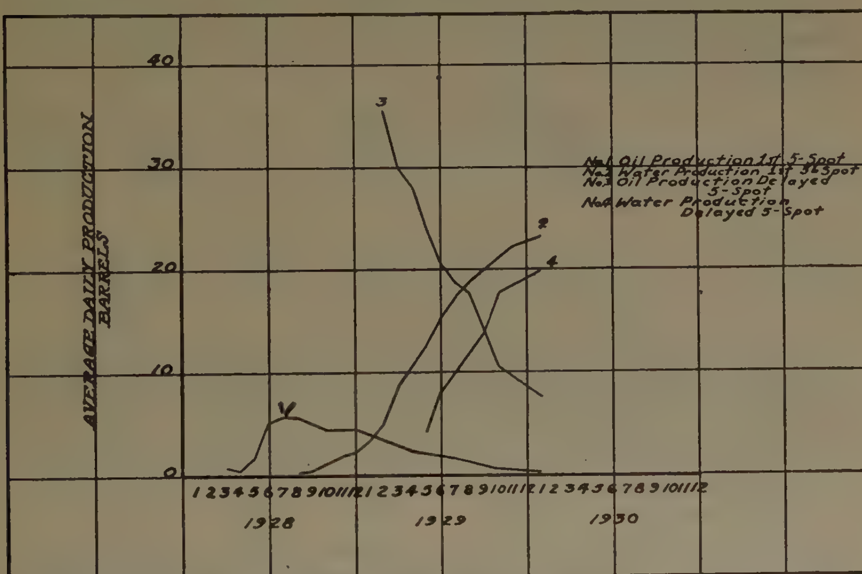

FIG. 7.—WATER AND OIL PRODUCTION OF DELAYED FIVE-SPOT IN COMPARISON WITH WATER AND OIL PRODUCTION OF ORDINARY FIVE-SPOT.

within a reasonable period of time, the high-porosity sand will take so much water and will flood so much faster that it will soon become uneconomical to handle the large volume of water coming into the producing well, and it must be abandoned before the effects of the flood moving through the tighter sand will be noticed. If, however, the high-porosity pay in the lower part of the sand were completely saturated; that is, its capacity to hold fluid attained, and if the intake wells were forced to continue taking water by the application of additional pressure, the water would obviously have to start moving through the sand of lower porosity.

The results from this first experiment have been most gratifying. Not only was it found possible to saturate the sand with fluid to the point where it was impossible to put any more water into the sand, but the

production of the delayed five-spot well clearly shows, in comparison with the results obtained from the first five-spot, that the experiment had accomplished its purpose in forcing a more uniform flooding action throughout the entire sand body. The production curves of these two types of floods are shown in Fig. 7 and an analysis of the results obtained from them is given in Table 3.

Table 3.—*Comparative Results of Delayed Five-spot and Ordinary Five-spot Flood*

Delayed drilling has already increased the oil recovery on this property 159 per cent. and decreased the water production per acre 140 per cent. in approximately one-half the operating time.

	Time Flood Has Been in Operation	Area of 5-Spot, Acres	Total Oil Recovery from 5-Spot, Bbl.	Recovery per Acre, Bbl.	Total Water Produced from 5-Spot, Bbl.	Water Produced per Acre, Bbl.
First 5-Spot	23 months	1.43	1,815.35	1,269.4	6,350.0	4,440.5
Delayed 5-Spot	12 months	2.06	6,784.00	3,293.2	3,797.1	1,843.2

This first delayed flood, of course, has not yet reached a point where the ultimate recovery per acre can be exactly calculated. It is possible that it may not produce the oil indicated from the cores, but even if this recovery is not attained the success of the experiment is assured, for a previously unsatisfactory property has already been changed into a profitable investment.

The most obvious application for delayed drilling is upon properties where the porosity of the sand is decidedly variable. Under such conditions, the results from this one field experiment indicate that an increase in recovery of over 100 per cent. may be safely anticipated. Studies of cores taken in watered-out territory show that even in fairly uniform sands flooding action is far from efficient, and it is the writer's opinion that delayed drilling can be used to advantage under almost any condition, although there are few data to substantiate this idea.

The increased recovery that may be expected from delayed drilling is not its only advantage. Operating costs should be reduced, for the productive life of a delayed well will probably be much shorter than an ordinary five-spot well. In addition, it seems possible that delayed drilling will afford a control over production which is impossible under the present system of development, where the oil is pumped as fast as it comes into the hole. There seems to be no necessity for drilling the oil well immediately after the sand has been completely saturated, if market conditions are not favorable, and this potential production could

be securely held until a more opportune time, when it could be made almost immediately available with a material increase in profit to the producer.

Delayed drilling presents certain operating problems which are not encountered in ordinary intensive development. All old wells must be plugged in order to prevent any relief in pressure and, if the flood is drilled along a property line, arrangements must be made to delay the drilling of offset wells. It seems highly important that a uniform input of water be maintained through each intake well, for if the oil is not concentrated in the center of the five-spot it is questionable whether it can all be fully recovered. It should be appreciated that the production curve of delayed wells closely resembles the production decline curve of wells in a new field, and consequently a delayed flood should be equipped with the best material and machinery and sufficient tankage should be provided to care for a daily production far in excess of the production that might be expected from an ordinary flood.

Conclusion

It is rather difficult to appreciate fully the effect of water-flooding upon the Bradford and Allegany fields. Prior to the general application of water-flooding, properties were sold on a strictly production basis regardless of their acreage, or even for their junk value. The value of the Bradford and Allegany fields, based upon present-day prices for acreage, can be safely estimated at $350,000,000. Water-flooding has established a reserve of approximately 600,000,000 bbl. of recoverable oil in these fields, which would never have been obtained by natural methods of production. At the rate of their present production, a future life of 50 years seems assured. Each increase in the efficiency of water-flooding will have a material effect on prolonging the life of these fields by making more oil available to meet the demand for Pennsylvania crude.

The water-flooding of oil sands is by no means restricted to the Bradford and Allegany fields. Experimental water floods are in operation in many other fields in Pennsylvania, with variable but in general rather encouraging results. There are undoubtedly many sands in the Appalachian fields that could be adapted to water-flooding and consequently a much wider application of this method for increasing oil recovery may be expected in the future.

DISCUSSION

H. H. Hill,* New York, N. Y.—Mr. Torrey raised one point in his paper that I would like to have comment on; that is, delayed drilling, saturating the sand with water and later producing the oil. The idea has been prevalent for years that in many old fields wells should not be shut down on account of the water.

* Petroleum Engineer, Standard Oil Development Co.

P. D. Torrey.—There is one bearing that I did not comment on, that the production curve of delayed drilling wells is going to be different from the production curve of the ordinary five-spot. In sands of much higher permeability than the Bradford, it might be possible to get gravitational separation and segregation of oil and water, which apparently we have not found in the Bradford field.

H. H. Hill.—Take the Bartlesville sand wells in Oklahoma, for example. Everybody says those wells should be operated continuously because otherwise the water will drown them out. Will the water in the sand help to drive out the oil?

P. D. Torrey.—That will depend on whether there is an outlet. It seems that in so far as experiments have been made in Bradford, letting the well stand would have no harmful effect on it there; but I would hesitate to apply that to other sands and formations with which we are not so familiar.

F. M. Brewster,* Bradford, Pa.—In delayed drilling the producing well is not drilled. In other words, take a five-spot; there are four water wells into which water is put to force the oil to the center, but there is no oil outlet; therefore, no migration of water through that to the point of production. In the Bartlesville field, if the wells are shut down the water can go through one stratum of sand, and then might backflow into another stratum.

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* General Manager, Belmont Quadrangle Drilling Corpn.

Chapter VI. Valuation Methods

Valuation of Flood Oil Properties*

By Eugene A. Stephenson† and I. G. Grettum,† Pittsburgh, Pa.

(New York Meeting, February, 1930)

Abstract

The flooding process was originally the result of accidents to casing and tubing, but it has gradually passed from an accidental condition to a definite engineering procedure. In spite of the general sheetlike character of the major sand body, the position of shale bands, their thickness, the size of the grain and variations in effective porosity all give the sand different characteristics in different layers and in different places in the same layer. This condition has an important influence on the movement of flood oil and water, and on the yield per acre, as well as a bearing on what shall be considered the best method of handling flood wells.

A valuation takes into consideration six factors: (1) Flooding methods, of which four have been in common use, as follows, in order of effective recovery, (*a*) circular flood, (*b*) line flood, (*c*) five-spot and (*d*) five-spot with delayed drilling; (2) recovery per acre, which is definitely related to the oil content, the porosity, the method of flooding, the spacing program, and the continuity of the water supply; (3) the rate of production per well per day, which is definitely related to the method of flooding, the oil content and the porosity of the sands; (4) the operating cost of the well, including royalty, overhead, taxes, etc. (Operating costs are usually expressed as unit cost per barrel.); (5) the expected price per barrel. It is safer to use the average price over a number of years than to attempt to forecast future price fluctuations.

The discount factor (the sixth factor) used in appraisal of Bradford flood properties should be less than that commonly applied to other properties, because the hazards of operations have been reduced almost to those of a manufacturing industry.

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* This paper is available at the office of the Institute as *Technical Publication* No. 323.

† Associated with Ralph E. Davis, Engineer.

DISCUSSION

S. C. Herold,* Los Angeles, Calif. (written discussion).—The authors remind us of a question which may be raised concerning the meaning of "recovery of oil per acre." The expression is probably inherited from the mining industry. It is a simple matter to conceive of 10,000 tons of ore per acre, but how shall we form a definite conception of 10,000 bbl. of oil per acre? Oil flows. In hydraulic and volumetric controls a hole 20 sq. in. in area can produce all the recoverable oil from an area of, say 10,000 acres, given a proper location on the structure and sufficient time on production. Does the fact that an operator owns 1, 5, or 100 acres mean anything in particular with nature? In capillary control the drainage space by natural flow is a circular cone, while in forced drive operations the space is an elliptical prism, yet property is generally bounded by straight lines placed without regard to this drainage. The expression seems to have no definite meaning unless the amount specified pertains to the area actually drained and the space actually drained by the well or wells.

E. A. Stephenson and I. G. Grettum.—The use of the term "recovery of oil per acre" has come to have a specific meaning in flooding operations and applies to the total quantity of oil which has been recovered from any particular tract whose flood cycle has been completed. For example, if a tract of 25 acres has been flooded out and the oil recovered from the wells on this tract total 100,000 bbl., the recovery per acre is considered 4000 bbl. Whether or not complete drainage of all of the 25 acres has taken place, we do not know, although the probabilities are that undrained areas still exist. However, this does not change the fact that 4000 bbl. per acre have been recovered during the term of flooding operations.

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* Petroleum Geologist.

Mechanics of a California Production Curve

By Stanley C. Herold,* Los Angeles, Calif.

(New York Meeting, February, 1930)

Only two years ago there appeared in our technical magazines articles wherein it was shown that the application of back-pressure increased the ultimate production of a well, that edge water can be stopped in its encroachment by the injection of gas into the productive formation, with the consequent conservation of energy within the pool, that gas is the source of all energy involved in oil production, and that each pool has a definite minimum-valued gas-oil ratio to be attained for the most economical operation of wells. Today we are not so certain of these matters. Probably in some fields, under special circumstances, these ideas are correct, but certainly they must not be correct in all fields, under any and all circumstances. The nature of the productive structure, the location of particular properties on the structure, the existence of adjoining neighbors, whether these are higher or lower on the structure, and the methods of production followed by all operators on the structure, sand for sand on depth, make these subjects worthy of full consideration.

Our difficulties in analyzing and comparing the performance of reservoirs in various parts of the world do not rest solely upon structural features and property lines. We do not complete the list of causes for these difficulties if we add lithologic features and correlation of strata encountered by the drill, with the magnitude of pressures exerted by fluids within any of these strata. A further cause, one which the author believes will complete the list, is one involving the theoretical mechanics of fluids within porous formations—porous in the nature of interstices in sandstones and some limestones, networks of fractures in shales, and cavities in otherwise compact limestones.

The confusion of ideas concerning reservoir mechanics still with us today seems largely due to our failure to recognize among all wells three great divisions of theoretical mechanics, three great systems which are distinct in themselves, and according to which each well, or better, each group of wells, must be analyzed separately. These systems have been named by the writer Hydraulic Control, Volumetric Control and Capillary Control, respectively.[1] Wells in these controls behave dif-

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* Petroleum Geologist.

[1] S. C. Herold: Analytical Principles of the Production of Oil, Gas and Water from Wells. Stanford Univ. Press, 1928.

ferently, and they must be handled differently, to get the best results in production practice, taking into consideration the other features of structure, property lines, lithology, correlations, pressures, and, in addition, any peculiar conditions displayed by the individual wells of any group—conditions that make them appear to be different from all other wells in the world.

If we will recognize the existence of these three controls, our problems in petroleum engineering will be simplified. Perhaps some engineers today will not agree that the introduction of theoretical mechanics into petroleum engineering is a lead to simplification. The author has known theoretical mechanics as a difficult subject for several years; consequently he is inclined to be patient with those who complain about it, knowing that not yet is he himself 100 per cent. proficient in it.

California Wells

So far as the author knows, all wells in California are in hydraulic or volumetric control.[2] These controls can be illustrated by tanks for liquids (reservoirs of the open type) and by tanks for gases (reservoirs of the closed type). Where a rate of inflow of fluid equal to the rate of outflow is provided in these tanks, there is hydraulic control, and where a rate of inflow is either zero or less than the rate of outflow, there is volumetric control. With these California wells for the present may be included any other wells in the world where the oil is produced from formations post-Cretaceous in age.

Wells in the Mid-Continent and Eastern fields are in capillary control. This control can be illustrated by a Jamin capillary tube. With these wells for the present may be included any other wells in the world where the oil is produced from formations pre-Cretaceous in age.[3]

Back-pressures, offset wells and gas injection do not have the same effect in capillary control as in the other two controls. If we read articles written by engineers whose practice is confined to the Mid-Continent and Eastern fields, the features which they illustrate, and the methods which they find to be efficient, may be entirely inappropriate as applied to California fields. The reverse is equally true of the work of engineers in California as applied to Mid-Continent and Eastern fields.

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[2] Information at hand respecting Coyote Hills and Brea Canyon fields indicate that these may be in capillary control. For the present, they should be considered as possible exceptions.

[3] Wells with production from the Cretaceous may be in any one of the three controls. This classification according to geologic age is offered only as a tentative one. The control is a feature in mechanics, and if there happens to be an alignment with a geological division, it is incidental. Older porous rocks are more compact, or more firmly cemented, and their surface exposures, when present, do not appear at elevations sufficient to furnish a fluid head capable of overpowering Jamin action in the compact formation.

Type Reservoirs

The principles of production are usually explained by means of illustrations or diagrams of artificial reservoirs—tanks either for liquids, for gases, or for both of these fluids. The reservoir may or may not contain sand to approach more nearly the situation as we know it to exist in many natural reservoirs. This method of expounding such principles is a good one, provided the proper sort of tank is used for the purposes of analogy. We cannot inspect in person all parts of a natural reservoir; we can only sense its characteristics at large by means of geological inference. Here it is easily possible to go wrong by selecting an improper type of tank for illustration.

A natural reservoir in California should be assumed to be a reservoir of the open type—one open to the atmosphere at some place other than at the well or wells where production is taking place—unless it can be proved by test in the field (and not by geological examination) that production comes from sealed lenses, or that the reservoir is one in capillary control. While these two exceptional situations may exist in this state, they may be ruled out for the present, in view of the fact that there is no absolute proof of their existence. From a geological point of view, the author accepts the fact that lenses exist in some of our formations. How well sealed they may be from a mechanical point of view is not known. It is certain, however, that most of our productive reservoirs in this state are reservoirs of the open type. Either the productive formation itself outcrops, or it is in communication with the surface by a fault or fault zone which reaches the surface directly or reaches a porous formation which does outcrop. The encroachment of edge water upon the pool at large is a proof of this fact, for such encroachment cannot take place in a reservoir of the closed type—sealed lenses and reservoirs in capillary control, as mentioned, wherein such reservoirs are not open to the atmosphere at some place other than at the well or wells where production is taking place.

For the purposes of analyzing production in California, a tank system as shown in diagram in Fig. 1 is offered for consideration. The surge chambers contain air before the tank is filled with water. With the valve closed at the right, and with the tank filled to *A*, the air in these chambers occupies one-half its previous volume; the water line stands along a line *B*.

The air in the chambers possesses energy—energy derived from the water that is compressing it. It has no mechanical energy that can be said to be intrinsically its own, for that which it has is due entirely to the water. If we should connect one or more of these chambers with an air compressor, the best we could do would be to increase the head by the amount *B* to *C*. Thereafter air would simply travel to the tank and escape through the water.

The air in the chambers can perform work, if given the opportunity to expand. In this capacity it may be said to act as an agent for the water, inasmuch as it expends energy which rightfully belonged to the water. To get this performance of work we can open the valve and allow production to take place. Now the air expands in each chamber according to a kinetic pressure gradient, the upper line at B' which in this tubular system is a straight inclined line. During this expansion we obtain data for the curve MN. It is a straight inclined line appearing to approach zero production at a point N'. During this expansion, A, if it moves at all, moves very little. As soon as the kinetic gradient is established the internal conditions of production change. No more work is performed

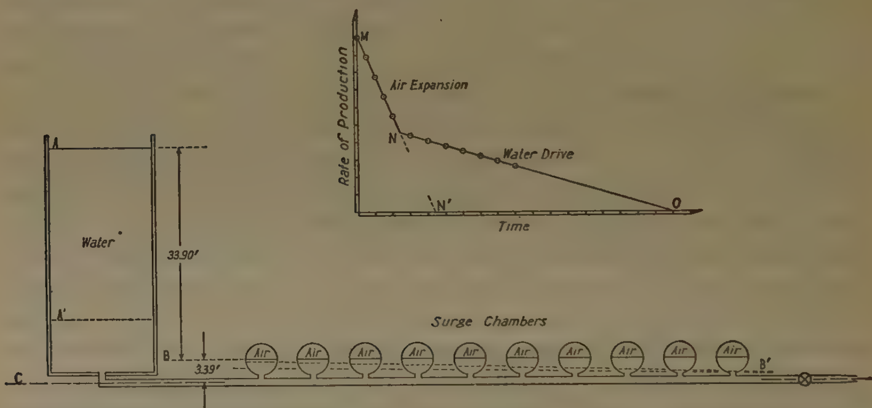

FIG. 1.—WATER TANK, FLOW LINE AND SURGE CHAMBER SYSTEM, WITH PRODUCTION CURVE.

by the air in the chambers; all work is now performed by the water; A lowers in accordance with production and B' lowers correspondingly with A. At a position A' we find a gradient such as the lower line at B'. The air in the chambers now expands only to accommodate itself to lowered pressures exerted by the head of water. The system produces solely by water drive, and the data of production gives us the straight inclined line NO.

It is worth while emphasizing here the fact that mere expansion of air does not imply work performed. Air can expand without performing work. If it does work it loses heat and drops in temperature; otherwise it retains its heat. Heat energy converted into mechanical energy is a measure of the work performed. Many writers make the mistake of assuming expansion alone as a measure of work performed.[4]

[4] The gas-lift involves the expansion of gas. The mere expansion is not a measure of the work performed in lifting the oil, but the loss in heat suffered by the gas on expansion is such a measure.

A California Production Curve

In Fig. 2 the line *ABC* represents the average of 127 producing wells in the Bixbee zone of the Long Beach field. The curve is drawn from actual field data. *AB* appeared to approach zero production at Nov. 25, 1928. It turned, however, to *C* in a direct line for zero production at June 6, 1929. Inasmuch as the productive formation contains both oil and gas, and as the gas can act in the manner of the air in Fig. 1, we are justified in claiming that *AB* represents production on gas expansion, where edge water, if it moves at all, moves very little, and that *BC* represents the water-drive, where water is alone in causing production; consequently where edge water must encroach upon the pool before the oil can be obtained.

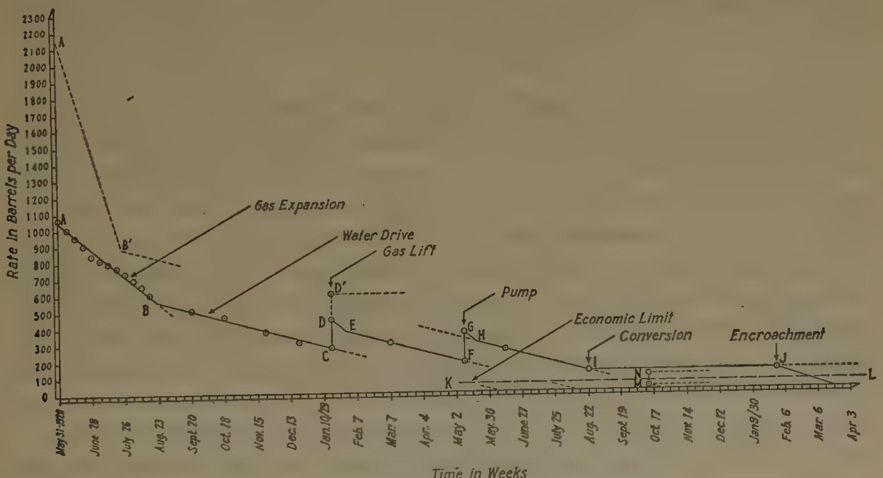

Fig. 2.—A California production curve

There is a difference between the systems of the two figures to be fully recognized. Air in the surge chambers stays where it is during the process of production, expanding as already noted. Gas in the Bixbee zone travels toward the well. Though the surge-chamber effect applies as well to one system as to the other, the "chambers" in the natural system are within the zone itself. In either system, the expansive fluid at a fixed distance from the orifice attains a state of equilibrium in accordance with the kinetic pressure gradient (a quadratic hyperbola in the natural system), and whether it is the same fluid or continually new fluid which adjusts itself to this gradient makes no difference. Expansion takes place without the performance of work.

It must be admitted, of course, that a continual supply of gas will furnish the energy for a gas-lift if the wells are properly equipped for it. But we are considering here the mechanics of the reservoir interior up

to and including the "orifice" at the bottom of the well and not the mechanics of any "heat engine"—which a gas-lift is—exterior to such an orifice, within the vertical hole of the well.[5]

At Jan. 17, 1929, the conditions of production were gradually altered. Natural flow at many of the wells had reached an undesirable low point, and one well after another was placed on gas-lift. On account of the erratic nature of the subsequent data of production, the author has chosen to use imaginary data after the point C was reached, considering all wells to be treated simultaneously alike. The lift raised the curve, we will say, to D. This established a new condition for the surge chambers within the zone; the gas was able to expand and perform work once more, in order to establish a new kinetic gradient. The production curve takes a path DE parallel to AB, where it meets at E a line EF parallel to BC, whose position is determined by observation on March 7.

Gas Injection

If we suppose gas injection to have been installed at the time the wells were placed on lift, the rate would have been raised to some point D', and if the injection is properly regulated a horizontal straight line out from D' is for a time possible. By connecting the surge chambers in Fig. 1 with a compressor, we can raise temporarily the rate of flow from the orifice, because of friction in the line from the tank. Clearly our line would soon fill with air and we would get no more water. The same thing seems to happen in a system such as the Bixbee zone. We would fill the zone with injected gas and eventually cut off the oil. We would in the first system hold back the water in the tank and in the second likewise hold back the edge water. It is easy to see, of course, that by holding the edge water those wells in the zone located just within the edge of the pool are maintained in oil, whereas they would otherwise go to water.

Location on structure with respect to neighboring properties plays an important role in the case of injection in this state. If there are no neighbors, no losses are suffered by injection; all is on the credit side on account of an increased rate of production from the output wells. But in Long Beach all operators have neighbors.

Where wells are producing from reservoirs of hydraulic and volumetric controls, the gas is free to slip around through the zone in accordance with any upward trend of the formation on structure. The injection of gas on the top of the structure places large bubbles at the top, and these, of course, tend to remain there. On the other hand, gas that is injected on the flank of the structure tends to move up to the top,

[5] Engineers are now recognizing the fact that the gas-lift is a mechanism apart from any directly related to the theoretical mechanics of the natural reservoir, and that the two features must be analyzed and considered separately in the field.

being aided in its movement by radial flow toward all wells in the zone. It is possible to sum up the consequences of injection in reservoirs of this type as follows:

Location on Top of Structure.—Replacement of oil by gas in the zone underlying the property. Maintenance of edge water down the flank so that neighbors stay in oil. Loss of gasoline by injecting gas sufficient to extend to adjoining wells. Increased rate of production from output wells.

Location Down the Flanks of Structure.—Creep of injected gas upward, carrying its gasoline, to the neighbors on the crest. Maintenance of edge water off property lines. (Important in edge properties.) Increased rate of production from output wells.

Obviously it is a proposition of "give and take" in either case. It is impossible to say offhand whether or not the gains offset the losses with a particular piece of property. If we have the data of production before and after injection, with the data of injection itself, also the contour map of the zone, showing the respective property holdings, it seems that a satisfactory conclusion concerning profits and losses incurred by injection can be deducted.

The Clean-up

In considering the zone as a unit, disregarding property lines within its area, all gas supposedly stored by injection within the productive horizon must come out before the zone is finally abandoned as depleted. Water must be allowed to replace the oil of the pool. Nature is flooding the formation for us. She sweeps the oil horizon clean—cleaner than many of us familiar with conditions in capillary control are ready to believe. If we attempt to replace oil with gas we can not sweep the horizon clean. Globules of oil will remain within the formation. (The author's estimate is 20 per cent. of the pore space to remain filled with oil.) With water there are no globules left behind. The grains remain "painted with oil," but this paint is not liquid, any more than the paint on a house. It is held to the grains by adsorption; its presence is never reflected in the production curve, for it does not move toward and out of the well.

Pumping the Well

Returning to Fig. 2, we may imagine production to proceed to *F*, where the pumping stage is reached. While the gas-lift removed only a part of the weight of the oil column off the bottom of the hole, a pump can be arranged to remove more, if not all of this weight. The process at *CDE* is now repeated at *FGH*. An observation on June 13 establishes the position of *HI*.

Conversion of Control

If, in Fig. 1, we were to provide an inflow of water at the top of the tank, *A* would immediately proceed to move upward or downward and assume a level where the rate of outflow just equals this rate of inflow. A system previously declining in volumetric control thus is converted to one which does not decline in hydraulic control. Where the curve of production changes from a straight inclined line to a straight horizontal line there is a point designating a "conversion of control."

The Bixbee zone is in communication with the surface—exactly where, it is not possible to say.[6] Presumably water can and does enter the zone from the surface, as it is known to do at the Kern River field. Then at some point *I* or *M* on the production curve, the rate of production will travel along a straight horizontal line, conforming to a conversion of control. The total rate from the zone will just equal the rate of inflow. If winters are comparatively dry the rate will lower, and if they are wet, the rate will rise, as it does in the Kern River field.

It is not suggested that such a conversion has already happened at Long Beach, Bixbee zone. Perhaps *D* and *G* are too low, placing *I* and *M* too far to the left according to the dated axis. Subsequent to *C* the curve has been entirely imaginary. Of course, any inadvertent shifting of dates will not affect the present argument.

It cannot be said in advance whether the conversion will take place at *I*, above a line *KL* representing the economic limit of production, or at *M*, below such a line, because the rate of inflow is not known. To determine the fact we must await observation on the behavior of the well. If the curve does not proceed to the axis, as shown on October 24, we can be assured that there is conversion, and the observed rate gives the position of the horizontal line. If the point of conversion is below *KL*, the remedy is simple. We need only shut in all wells except a few at the crest of the structure, raise the rate in this manner from *M* to *N*, and take out the remainder of the oil in the pool.

The pool diminishes in size to the last; water continually advances. Even top wells must eventually show edge water. At *J* it is shown to have reached a stage near the finish. More and more water comes to the well; in the end an inclined line (not necessarily straight as represented) reaches *KL* and we are finished with the zone. For the Bixbee zone, such a point as *J*, whether on the elevation of *I* or *N*, should more properly be placed 10 years or so to the right of the position shown.

It is on this horizontal line representing the final cleanup that all gas once injected into the zone comes out to allow replacement by water.

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[6] A measurement of the closed-in pressure when the zone was first put on production would have given the location with respect to elevation above the sea. This elevation might have given some clue as to the probable geographic location.

With injection, as at D', the curve of production becomes somewhat erratic, for nature is thrown off her intended path. In the final stage the line KL is reached sooner but the curve is held higher. The area subtended by the curve is the same with or without injection, since this area represents oil taken out of the pool.

We have not made oil by raising the curve; we have realized profit at a greater rate, and this is not to be ignored. The ultimate production is not affected by injection.[7] We dodge the economic limit when we come to it. It is safe to assume that the few barrels of oil finally left in the zone will be the same in number whether injection is or is not used.

Raising the Curve

If areas subtended by curves represent oil taken out, we should, in the presence of neighbors, raise our curve as soon as possible, taking into consideration all the economic questions necessarily involved. Truly, nothing is gained on our neighbors if we all do the same thing with our wells—we only change our rate of income when we act in unison. If a representative well in Fig. 2 were placed on the pump in the beginning the curve would be something like $A'B'HI$. B' lies to the left of B, for the action of the water-drive would come sooner. Correspondingly, any back-pressure applied to the well by flow-nipples would lower AB, make it flatter, and place B' to the right of B. (This feature is not shown in the figure.) It is apparent that we should not hold our curve on AB while neighbors are holding theirs to $A'B'$; or that we should not hold our curve below AB by back-pressure while neighbors are holding theirs to AB.

As with gas-lifts and pumps, back-pressures do not affect the ultimate production from the zone. They only extend the point J farther to the right, meanwhile permitting other wells to produce a greater portion of all the oil in the zone.[8]

Ultimate Production

The ultimate production from any particular well is one thing, being dependent on its location on structure and the production methods employed at all wells in the zone, while the ultimate production from the entire zone is quite another thing.

It is supposed that, inasmuch as a structure is not of perfect geometrical design, roof pockets will exist here and there, perhaps between wells, and if this is the case, injected gas will dislodge any oil in them and shove it to the well. Undoubtedly such pockets exist; any oil they may have

[7] Injection does affect the ultimate production from wells in capillary control, and injection in this case would be termed more correctly "a forced drive by gas."

[8] Statements in this paragraph must not be construed as applicable to wells in capillary control.

had has been replaced already by gas which has been liberated from solution on the decrease of pressure in accordance with a kinetic pressure gradient established by the adjoining wells during the period represented by *AB* in Fig. 2.

Gas-oil Ratios

A great deal has been written and said about gas-oil ratios of late. The significance of those ratios may be one thing in California and other fields wherein a water-drive is substituted for gas expansion, and another thing in the Mid-Continent and Eastern fields wherein gas expansion is the exclusive agent of propulsion.[9] In view of the foregoing analysis of a production curve in California, the author offers the following interpretation of gas-oil ratios applicable here, realizing that the picture as presented may not be complete, and in consequence may not be exactly fair. The subject is a complicated one, and all facts concerning it cannot be learned in a brief time.

During the period of gas expansion, gas-oil ratios are of importance. If this gas were allowed to escape, *AB* would be inclined more steeply, *B* would be located on the same line *BC* extended to the left of the position shown. The water-drive would come into action sooner, and the area under a definite portion of the curve such as *ABC* would be smaller, representing less oil produced previous to January 17. During the water-drive gas-oil ratios have no significance to which any value may be attached.[10] During the gas-lift stage they have no significance except the one requiring the addition of more gas for the lift in case of a deficiency. During the pumping stage they have no significance except for the fact that the gas must be bled off in case of an excess, so that oil can enter the pump chambers properly.

Finally, during injection, gas-oil ratios have a significance of value. They show how much gas there may be injected in excess of that actually needed. They indicate how much gas is being "stored" temporarily in the productive zone, to be drawn off at a later time.

A Test in Mechanics

As stated in the beginning, this problem concerning the mechanics of a California production curve as here presented depends on the fact that the zone constitutes a reservoir of the open type. Long Beach, Santa Fé Springs, Dominguez, Kern River, Coalinga, Kettleman Hills

[9] This is a fundamental difference between reservoirs of the open and closed type respectively; that is, between hydraulic and volumetric controls on the one hand, and capillary control on the other. If there are mechanically sealed lenses these are of the closed type, but in volumetric control. Gas-oil ratios have more or less the same significance here as in capillary control.

[10] As before, the gas-lift is considered as a problem apart from the problem of the reservoir. In the gas-lift the ratios have continual significance.

and Ventura fields have reservoirs which are undoubtedly of this type. For possible exceptional cases the following test is suggested, in case determinative data are not already at hand:

Pump up the reservoir at one well with gas, stopping pumping operations from time to time in order to allow an attached pressure gage to come to rest. (Incidentally note any changes in pressure at adjoining wells which should be closed.)

1. If the curve obtained by plotting pressure against volume pumped in is a straight horizontal line, the reservoir is of the open type.

2. If such a curve is a straight inclined line, the reservoir lies within a lens which is entirely sealed from a mechanical point of view.

3. If such a curve is a parabola, the reservoir is one in capillary control.

In making such a test we should allow for an erratic behavior in the beginning of operations. We may increase the head a little in case 1 by shoving the free surface of oil down the structure, a phenomenon corresponding to an increase of head from B to C in Fig. 1. Again, we may set up a high resistance due to Jamin action in the vicinity of the well, by filling an excess of pores with gas. Beyond a reasonable distance the introduced gas pushes oil against bubbles already existing within the formation, compressing them without adding to their number.

Forecasting Production

Well records in California frequently show a general feature like the bend in the curve-section ABC. Such a bend may not be sharp at B. Perhaps the gas-lift action is undergoing a change which gradually increases the weight of the vertical column of oil bearing on the bottom of the hole, tending to round off the bend. At other times we deliberately round off corners of curves by eye, with the idea of averaging the situation.

It frequently happens that the progressive development of a new zone, especially where property holdings are small, causes AB to fall more rapidly than it would otherwise. The section of the curve in this case is not solely reflecting the surge-chamber effect. The drop due to new wells is one that would take place in the complete absence of gas.

The records of many wells in this state show an unbent straight line. We can only decide here between sections AB and BC according to the gas content of production with oil.

The lifting of the curves by gas-lift and pump should not be ignored in forecasting. The section of the curve from B to I should not be smoothed out; it would be better to raise the curve abruptly, parallel to itself.

The production curve method seems to be entirely appropriate so long as conversion to hydraulic control has not taken place. Fore-

casting after conversion must be done by means of the contour map with data on encroachment up the flank.

The entire curve from A to J if entirely smoothed out would approach the appearance of a hyperbola, except for the cutting of the axis on the left. The use of a hyperbolic equation, and the use of an exponential equation as well, for the purpose of forecasting is proper, but only so on account of convenience. It must not be supposed that either the hyperbola or exponential curve has any significance pertaining to the mechanics of production.

In forecasting production from any group of wells, considerably more weight should be given to recent data than to earlier data. Sometimes it is preferable to ignore the earlier data completely. We have relied too strongly upon the idea of a "family curve" of production. The curve undoubtedly has some significance, but not the universal significance frequently attributed to it in the past.

DISCUSSION

A. H. Bell,* Los Angeles, Calif. (written discussion).—Mr. Herold infers that the ultimate production of a pool is not increased by gas injection. This is apparently based upon tests made with air and water in small equipment, which overlooks three important factors in actual field practice: (1) gas used for injection is soluble in the oil in the formations; (2) the encroaching water is not soluble in the oil; (3) the sands and shales through which the oil, water and gas must travel prevent their performance according to theoretical rules.

When gas is injected into an oil sand at pressures from 500 to 1500 lb. per sq. in. this gas is partly absorbed by the oil, so that as it travels toward an area of low pressure the reconversion to the gaseous state causes acceleration and a drive of the more sluggish particles toward the well. In addition, and of lesser importance, the solution of gas and oil has a lower viscosity and is retarded less by the sand in its movement.

The tendency of water to "come up" at a well and cause production of clear water while oil is retained in the areas between wells has been established in California and it is very doubtful whether the natural edge-water drive under actual field conditions, without injection, cleans up a sand as well as Mr. Herold believes. By holding the pressure in the sand with gas injection the chances for stratification necessary for complete removal of the oil are enhanced. The undisturbed areas between wells must be thrown out of balance by some outside media in order to secure a complete removal of all oil in the pool, and injection offers the best means at present for this purpose.

The encroachment of water upon the sides of a structure does not occur as a level and even movement as it would if oil and water only were put in a vessel in the laboratory. The differences in porosity cause more rapid encroachment of water between certain layers of shale, with the result that the wells may go to water in the middle of an oil measure, with clean oil remaining above and below. Due to the reduced friction of the water through the sand, this water will have a higher head than the oil, although both are backed by the same edge water. Injection may be used effectually to increase the pressure in these oil zones so as to counteract the pressure of the edge water and allow considerable oil to be produced that would other-

* Production Engineer, Continental Oil Co.

wise remain in the sand, while the well produced all water. These conditions are not theoretical, but have been actually encountered in California fields similar to Mr. Herold's examples.

F. G. Tickell,* Stanford University, Calif. (written discussion).—Mr. Herold has defined[10] "capillary control" as operative under conditions where external pressure on the fluids in the reservoir is not sufficiently great to overpower the resistance due to Jamin action. In volumetric and hydraulic controls, on the other hand, the external pressure of edge water is stated to be capable of overpowering this resistance. One condition is claimed to be exclusive of the other.

In the present paper, Mr. Herold apparently claims that a California well starts in capillary control and abruptly changes over later to volumetric control.

Granting, for the purpose of simplifying this discussion, that internal resistance in an oil and gas sand is due to the Jamin effect, and that edgewater head is the source of the pressure in all California reservoirs, it does not seem to be demonstrated that the period of production up to the time of application of the gas-lift, as illustrated in Fig. 2, is a *discontinuous* function, composed of the essentially straight limb of a hyperbola on the left side and of a straight line on the right side. It seems more probable that production is principally actuated at the start by gas expansion, but that this influence gradually diminishes and the effect of water encroachment gradually increases, with time. Certainly the rate of depletion of gas pressure is somewhat retarded by the slowly encroaching edge water. There is no reason for assuming that the edge water part of the sand has as great permeability of an oil-reservoir part, but it must be permeable to some degree, and the edge water must start to encroach as soon as pressure is relieved within the reservoir.

The most probable condition, as stated elsewhere,[11] is that the control is a combined one and that unaided production is a *continuous* function of time. From an inspection of Fig. 2, it is no more evident that two curves should be drawn through the first 17 of the plotted points than that one curve should be drawn. From a practical standpoint, perhaps, it does not matter whether we draw one curve or two; but for an explanation of the mechanics of a production curve, the distinction is worth while.

S. C. Herold (written discussion).—One condition is claimed to be exclusive of the other on the grounds that in one case the hydrostatic pressure is able to overpower the resistance due to bubbles and in the other it is unable to do so. Evidently Mr. Tickell believes that a situation may prevail wherein "able" and "unable" conditions exist simultaneously. Such a situation appears to be unreasonable and contrary to the law of the excluded middle in logic. The force of the water is either able or unable to push all oil and gas toward the well; it can be both able and unable to do so at any one instant. The idea of a combined control is an absurdity.

It has been admitted that conditions may change so that a force previously able to overpower the resistance is no longer sufficiently intense to do so. This change provides for a conversion of control at some instant in the life of the reservoir.

There is no intention to convey the idea that a California well starts in capillary control. It starts in volumetric control by gas expansion in the vicinity of the well. Possibly Mr. Tickell confuses gas expansion in the two controls. There is such gas

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* Professor of Petroleum Engineering, Stanford University.

[10] S. C. Herold: Analytical Principles of the Production of Oil, Gas, and Water from Wells. Stanford Univ. Press, 1928, 417–418.

[11] F. G. Tickell: Capillary Phenomena as Related to Oil Production. *Trans.* A. I. M. E., Petroleum Development and Technology, (1928–29) 343.

expansion in both, but in volumetric control gas expansion is replaced by water drive, whereas in capillary control the well completes its history entirely on gas expansion.

Mr. Tickell's question regarding the possibility of a discontinuous function is well taken. It will be necessary to rely upon experiments with such an apparatus as described in order to answer the question. I believe there is clear and sufficient evidence of a discontinuous function, although various experimenters may wish to regard such evidence differently.

Mr. Tickell says that edge water must start to encroach as soon as pressure is relieved within the reservoir. Pressure, however, is not relieved instantaneously throughout the entire natural reservoir. Time is required for the release to reach the edge water. This is the time of gas expansion.

Mr. Tickell says further that in Fig. 2 it is no more evident that two curves should be drawn through the first 17 of the plotted points than that one should be drawn. If we were to confine our analysis to one set of points alone, I believe we would not be justified in claiming two lines. As a matter of fact, however, any set of data from California wells shows the same feature. There must be a reason for it. I have given it one interpretation; if there is another equally logical, and equally proved by experiment, I trust that some one will state it. If this other interpretation seems better, I shall be happy to accept it and discard mine.

Chapter VII. Miscellaneous

Methods of Tubing High-pressure Wells

By H. C. Otis,* Shreveport, La.

(Tulsa Meeting, October, 1929)

During the past year or two considerable time and money have been spent in developing equipment for tubing large-volume high-pressure oil and gas wells without loss of production. That the efforts have met with success is proved by the fact that any properly cased well, regardless of its production or regardless of its rock pressure or working pressure, can now be safely tubed with no appreciable loss of production, provided experienced crews handle the new equipment.

It is conceded that a far better gas-oil ratio can be secured by flowing a well through tubing of a proper diameter—the diameter of the tubing depending, of course, upon the volume of fluid and gas and the depth of the well—than by the more usual method of installing a choke at the mouth of the well. Where possible it is becoming the practice to bring wells in through tubing, though in the majority of instances this is not feasible. In many instances it has developed, after a well has been brought in through tubing, that the tubing installed is either too large or too small for the most efficient operation or that the well had not been drilled deep enough.

The equipment described in this paper, in the hands of experienced men, permits the tubing of these wells after they have been brought in, with the size of tubing then determined by actual observation to be best suited for each particular well, and with no danger of the well getting out of control, of catching fire, of drilling itself deeper, or of any loss of production. The deeper the flowing production with the consequent future higher lifting costs, the more essential it is that the size of tubing used be such as to give the best possible gas-oil ratio. The ability to bring in these deep wells through the casing and then, immediately after their completion, regardless of volume or pressure, to tube them with the size of tubing that permits the most efficient use of the gas present will doubtless save many dollars.

Uses for the New Equipment

The equipment permits a further step in the operation of wells where the conservation of gas is of major importance. Perhaps 3-in. tubing

* Arkansas Natural Gas Corpn.

will give the most efficient operation at the outset in some particular well. After either the oil or the gas flow has declined to a certain point, 2½-in. tubing and later 2-in. tubing will be necessary to maintain that same gas-oil ratio. With the equipment described, it is possible to plug the tubing in the well, to snub it out of the hole and then to snub in pipe of the proper size; all with no waste of production and with no danger to the workmen or to the well. The reverse operation is at times desirable. By agreement production may be curtailed to the point where 2-in. tubing gives the desired ratio. Later, restrictions may be lifted so that 2½-in., 3-in. or 4-in. tubing may be used. This desired change can be readily and safely effected.

In other instances, where flush production is known to pass off quickly and is followed by the use of air-lift, and where the field is under severe competition, the ability to tube the well for the use of air-lift before the natural flow has declined has a distinct value in that it permits the use of a gradually increasing amount of air or gas to augment the supply of gas in the sand as it diminishes—never permitting the flow of oil to stop. It is the usual practice now to permit the natural flow to continue until it stops, then to tube the well and again start the flow into motion with either air or gas. Theoretically and practically this practice of permitting the flow of oil to stop for even a few hours is bad, and is not necessary.

The production of high-pressure natural gas also carries with it situations under which the ability to tube or siphon a well, regardless of its pressure or volume, without permitting the escape of any appreciable amount of gas during the operation, is of extreme value. Water troubles are not confined to low-pressure small-volume wells. The Richland Parish, Louisiana, gas field is a striking example of such a situation. Here wells of from 50,000,000 to 60,000,000 ft. open-flow capacity with rock pressures up to 1100 lb. are the rule. After a comparatively short pull, water puts in its appearance, not in large quantities but rapidly enough, in the course of a month or so, to build up a head in the well that seriously effects its working pressure and delivery capacity. It is not safe, because of danger to the well connections and the almost certainty of drilling the well deeper, to open these wells into the air to remove this accumulated head of water. Siphons then are necessary to successful operation. For various reasons the wells are not brought in through tubing, so tubing must be run after completion of the wells. Any method of siphon installation that would permit the escape of gas and sand would be almost certain to end in disaster, therefore the operators have welcomed methods of installation that permit the safe, even if not advisable, lighting of a cigarette only a few feet from the well connections at any time during the installation.

There are also other uses for the equipment. Occasionally, in rotary drilling, a well blows in with no liner in the hole. This, of course,

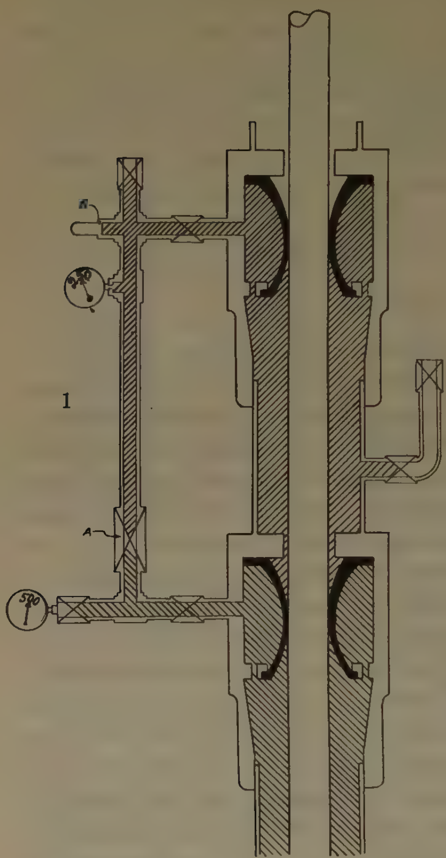
often happens in cable-tool drilling. As much as 100 ft. of liner or screen of the desired diameter can be run to bottom, with the well feeding through the side connections or not, as may be desired, during the operation. Occasionally a well blows in with the drill pipe still in the hole. It is not as a rule a difficult matter to plug the bottom joint by use of a small packer and then to snub the pipe out through control heads—all without loss of production.

Description of New Equipment

Control Heads

There are two general types of tubing control heads (Figs. 1–3), each of which has its advantages and disadvantages. In one of these types a gastight or fluid-tight seal around the pipe being run is maintained by a rubber ring forced tightly against the pipe by the gas or fluid pressure in the well. This rubber expands to permit the passage of couplings. As long as this rubber remains intact, no material leakage can take place. The advantages of this rubber-packed type lie in the fact that the well itself furnishes and regulates the pressure which forces the packing against the pipe and in the fact that there is no delay in passing couplings. One disadvantage lies in the fact that since the rubbers must be flexible enough to expand and allow passing of the pipe couplings, it follows that there is a limit to the thickness and consequent strength which can be built into them. Experience seems to indicate that they are not safe, particularly on long strings of upset pipe, for working pressures over about 300 lb. Two makes of control heads of this type allow for the use of two rubbers, on the theory that double protection is thus afforded. The installation of a regulated by-pass from one head to the other, having the effect of stepping down the effective pressure against each rubber, materially increases the working pressures against which this type of head can be used. A further disadvantage in the use of these heads lies in the fact that if, during the snubbing operation, the pipe should get out of control and start out, there is nothing built into the head itself that will prevent its being blown clear out of the hole. One specialty company, I believe, is attempting to work out a model that will remedy this disadvantage.

The other type of control head uses steel rams, bored to completely encircle pipe of the desired diameter and faced with sections of hydraulic or composition packing. These rams are manually forced against the pipe being run by various screw mechanisms, and a shut-off secured, to any desired degree. It is necessary to use two of this type of head on each well, to permit the passage of couplings, for if one alone were used, when it was opened to permit the passage of couplings the well would be free to blow into the atmosphere and would soon blow out the



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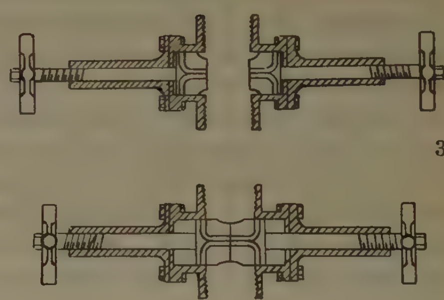

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FIG. 1.—TWO LOW-PRESSURE TUBING CONTROL HEADS MOUNTED TOGETHER WITH REGULATED BY-PASS.

Well pressure assumed to be 500 lb. Lower area (lines running left to right) is under 500 lb. pressure.

A = small spring-type regulator, maintaining 250 lb. on outlet side, causing upper area (lines running right to left) to be under 250 lb. pressure.

Relief valve *B* set at 260 lb., to relieve excess pressure set up either through failure of regulator *A* or through leakage between tubing and lower control-head rubber.

There is then exerted against outside of lower rubber a pressure of 500 lb. and against inside of this rubber a pressure of 250 lb., resulting in an effective pressure of 250 lb. against this rubber. A similar effective pressure of 250 lb. is exerted against upper rubber, 250 lb. being against its outside and atmospheric pressure against inside.

FIG. 2.—LOW-PRESSURE TUBING CONTROL HEAD.

A, tubing; *B*, control-head rubber; *C*, casing or well connections. Gas or fluid pressure from well forces rubber *B* against tubing *A* and makes a seal between tubing and rubber.

FIG. 3.—HIGH-PRESSURE TUBING CONTROL HEAD.

In upper drawing, rams that form gas or fluid-tight seal around tubing are open; in lower drawing, they are closed.

packing, and if sand were present would soon ruin the face of the rams. This type of control head can be built to withstand any desired pressure and has the further advantage that if the pipe should start out of the hole it could not move for more than the length of one joint, because, when the rams are in the closed position, a coupling cannot pass through them. Since, however, two sets of rams must be manually opened and closed for the passage of each coupling, this type of control head is slower in operation than the first type mentioned. Either type, when used with the snubbing and packing assembly to be described later can be repacked in a few minutes at any time during the running of the pipe, and either type of head can be salvaged after the pipe has been landed on bottom.

Snubbing Equipment

Installing tubing against working pressures in excess of 1000 lb. necessitates the use of rapid and safe snubbing equipment. Approximately one foot of pipe of any diameter must be snubbed for each pound of working pressure on the well. From a rather crude start, a thoroughly reliable mechanism has been worked out. It has two principal members —the traveling snubbers and the stationary snubbers. The function of the former is the actual forcing of the pipe in against the well pressure, while the function of latter is to grip the pipe and prevent it from being blown from the hole while the traveling snubbers are being raised for a new bite. The stationary snubber is preferably bolted directly to the casing. A nipple with thick walls is screwed into the top control head, this being the top member of the casing string during the tubing operation. The walls are made thick enough for holes to be bored and tapped vertically for stud bolts which pass through the side members and hold the snubbers firmly in place.

One of the dogs of the stationary snubber is pivoted; the other is adjustable and not pivoted. The adjustable dog is held by two pins which extend from the side members through horizontal slots in the dog. By means of a hand wheel and screw, it can be moved toward the tubing to grip it tightly in cooperation with the pivoted dog or to back away far enough from the tubing to permit passage of couplings.

The pivoted dog is pivoted upon a pin immovably attached to the side members of the stationary snubbers. It is not adjustable towards or from the tubing, but can swing about the pivot pin to permit the tubing to pass downwards between it and the adjustable dog. The pivot pin is higher than or on a plane above the serrated portion of the dog, so that upward movement of this portion will also move it inward toward the adjustable dog, firmly gripping the tubing and holding it against upward motion through the snubber.

The pivoted dog consists of two members, one with an arcuate serrated face to bear against the tubing and pivoted upon or pinned to

the end of the other member, which is a lever or fulcrum and is itself pivoted or pinned to the side members of the stationary snubber. This flexible connection of the two members of the dog permits maximum gripping effect of the bearing face by assuring vertical alignment against the tubing.

The traveling snubbers are made up of two pivoted dogs identical with that used in the stationary snubbers. A cable passes from the lever end of one of these dogs down to a sheave pivoted in one end of a pair of casing clamps fastened immediately below the stationary snubbers, up through a tubing block or the center sheave of a traveling block, back down through a sheave in the other end of the casing clamp and up to the lever end of the other dog. Upward movement of the tubing or traveling block results in a downward movement of the traveling snubbers, which carry the tubing along with them. The stationary snubbers permit free downward movement of the pipe. When the traveling snubbers have been pulled down to the stationary snubbers they are raised for a new grip by lowering the traveling block. During this movement the stationary snubbers prevent the pipe already snubbed into the hole from being blown out again. After sufficient pipe has been snubbed in to cause it to fall of its own weight the snubbing equipment is easily removed so as not to interfere with the remainder of the tubing operation.

Device for Closing Bottom of Tubing

Various means of closing the bottom of the tubing to prevent flow of oil or gas through the tubing until after landing on bottom have been experimented with. The old method of simply inserting a thin cast-iron disk between two joints of pipe, this disk to be broken by dropping a weight from above, is not recommended because of the undesirability of leaving a weight in the hole, and the possibility of damaging the string of pipe or of damaging the screen, if one is used. Closing devices which require unscrewing to open after landing on bottom are objectionable, particularly when used with the smaller sizes of pipe.

A method of breaking a cast-iron disk from the underside, without dropping a weight from above or without screwing or unscrewing, has been worked out. The assembly consists of a forging of the same outside diameter as the couplings in the string and about 9 in. long. The upper end of this forging is threaded on the inside with a straight thread down to a shoulder, the inside diameter of this shoulder being the same as that of the tubing being run. A thin cast-iron disk and gasket are laid on top of this shoulder and a short combination nipple jammed against it to form a tight seal. A sliding nipple of the same inside and outside diameter as the remainder of the string operates in the lower part of this forging and is fastened in the forging by two dogs, which

operate both vertically and horizontally in slots cut in the forging. While running in the pipe these dogs are held to the left of the lower section of the slot. If the condition within the well is static, with no flow, the dogs will be hanging in the lower end of the slot, while if sufficient fluid or gas flow is present to raise the weight of the screen and anchor below, the dogs will be held up against the upper left-hand corner. The wedge on the bottom of the string is shaped roughly like a fishtail bit, any fluid flowing past it tending at all times to keep the dogs thrown to the left. A thin pointed steel bridge is built over the top of the sliding nipple. While the dogs are at the left of the slot this bridge cannot come up against the cast-iron disk. After the pipe is landed on bottom and the upper portion of the string turned a short distance to the right so that the upper portion of the slots is above the pins, the string drops approximately ½ in., causing its entire weight to be thrown upon the center of the cast-iron disk and easily shattering it. The thin bridge does not materially obstruct the tubing, and if any great amount of fluid or sand is following quickly cuts out anyway.

Operation of Tubing Equipment

The procedure is shown in Fig. 4, as follows: The tubing is lowered until it rests upon the bottom of the well. This does not telescope the tubing seal assembly and break the disk *G* because the pins *A* are not in position to enter the straight portion *B* of the slots. Measurements are taken, the

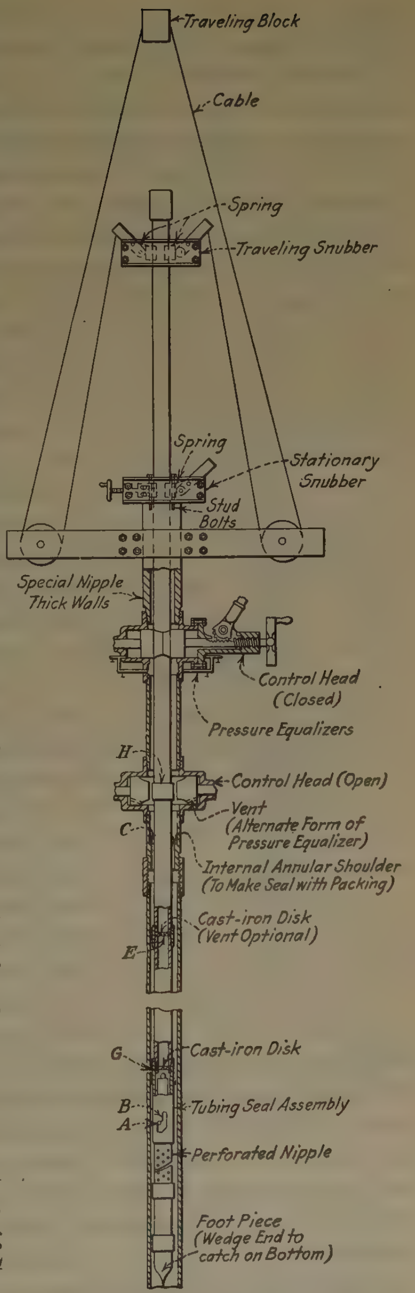

Fig. 4.—Order of procedure in using equipment.

tubing is raised, cut and threaded at a point which will be some short distance X inches below the internal annular shoulder C. A coupling and a tubing nipple about X inches long is then screwed upon the tubing where it was cut and threaded. A cast-iron disk E is made up here in the coupling, being held in place between the two pipe ends. This disk E may have a small bore or vent through it, the purpose being to permit some leakage at this point for determining by observation when the seal at the lower end of the tubing has been broken. Since the disk is loosely retained in the coupling between the pipe ends, the leakage around the edges may be sufficient when high pressures exist in the well; therefore the bore or vent may be desirable in some cases and not in others. It would usually be omitted when oil is present in high-pressure wells to prevent a spray of oil upon the workmen during subsequent operations.

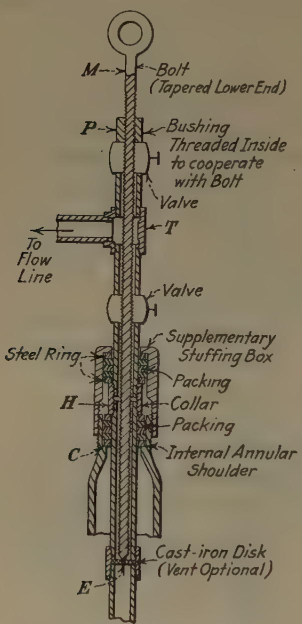

Fig. 5.—Fittings for tubing string.

More tubing is coupled to the string and it is again let down against the bottom of the well. The tubing is turned to the right at the top, and since the footpiece catching on the bottom of the well prevents the part below the seal from turning also, the slots B are brought over the pins A, allowing the pipe to drop, telescoping the tubing seal assembly and breaking the disk. The oil or gas in the well can then flow through the tubing up against the disk E. Its loose fit and the small aperture allow enough leakage to ascertain that the lower disk G has been broken. The tubing is again raised, two steel packing rings with packing between them are put around the tubing immediately below the coupling H and the tubing is again lowered. The steel rings are made so that they cannot pass through the inner annular shoulder C and the coupling H cannot pass through them. The weight of the tubing, therefore, compresses the packing between the outside of the tubing and the inside of the casing. The inner annular shoulder C must, of course, be small enough to prevent the passage of the steel packing rings. It may sometimes be in a nipple with the same exterior diameter as the rest of the string of casing, as shown in Fig. 4 or it may be, and usually is, contained in the narrow part of a swedged member as shown in Fig. 5.

After this packing operation is completed, the two control heads and everything else made up in the casing string above the packing may

be taken off. Then the part of the tubing string above the packing may also be removed. Gas from the well is leaking out of course, through or around the disk *G* from the time the lower disk is broken, but it is in such small quantity that it does not interfere with subsequent operations.

The fittings shown in Fig. 5 may then be assembled to the tubing string at coupling *H*. These fittings consist of the two valves shown and the T between them, which are permanent connections, and the bolt *M* and bushing *P*, which are used to break the disk *E* and then are removed. The well is connected to the flow line through the branch of T. Both valves are opened and the bolt *M* is screwed down through the bushing *P* until its tapered point bears against the disk *E* and breaks it. The well can flow out through the T and into the flow line. The bolt *M* is then backed up by unscrewing until the upper tubing valve can be closed. Then the bushing *P* and the bolt *M* may be unscrewed and removed and the end of the tubing permanently closed with a plug or cap, completing the operation.

If desired additional steel packing rings and packing between them may be put around the tubing above the coupling *H* to supplement the packing below. This can be tightened, as shown, by means of a member that screws down over the threads upon the upper end of the top member of the casing string, which will be threaded down far enough to give sufficient take-up in the stuffing box.

Time will not permit detailed description of the various other methods of using the equipment. Briefly, when it is desired to set liner in a producing well, one tubing control head is made up at the top of the well connection, four or five joints of 6 or 8-in. pipe are made up just above this, and two control heads and the snubbing equipment put in place. The liner is made up inside of the 6 or 8-in. running up into the derrick, and is connected to the tubing by a left-hand nipple, "J" tool, or any other of several possible methods. With the tubing control head that is immediately above the well fittings wide open, and with snubbing operations conducted from the top of the 6 or 8-in. pipe near the fourble board of the derrick, enough tubing is snubbed into the well to bring the top of the liner beneath the lower control head. This control head is then closed around the tubing, the few joints of pipe in the derrick are broken down, and the remainder of the snubbing operations are conducted from the usual platform a few feet above the floor. Recently 75 ft. of 4½-in. perforated liner was run in this way into a 45,000,000-ft. gas well having 750 lb. working pressure, with no loss of production. In this instance this was probably the only method by which the liner could have been put into the well. It could not have been dropped into the well while blowing because of the large quantities of shale and rock that would have been blown out and because of the certainty of gutting the well. Lubricating was not considered safe.

Pulling tubing or drill stem out of a well under pressure is accomplished by lowering a small packer through the tubing or drill pipe, the packer being run on a steel measuring line through a stuffing box. The measuring line is released when the packer reaches bottom and is pulled out of the hole. The packer is set by opening a valve on the tubing or drill stem just below the stuffing box, the differential set up by the flow past the packer expanding the rubber and effecting a seal. The pipe is then snubbed out of the hole, using the same equipment that is used to snub it in.

The equipment and process described, save for the control heads, were developed by the Southern States Co. of Shreveport, La. Patents have been applied for. During the past year and a half this company has successfully tubed over 150 oil and gas wells—wells under working pressures ranging from a few hundred to 1200 lb. per sq. in.—with virtually no loss of production in any instance. Against 1000 lb. or more an average of perhaps 12 hr. is required after setting up for running a 2000-ft. string and about 25 hr. for a 5000-ft. string.

Electric Welding of Field Joints of Oil and Gas Pipe Lines*

By Harold C. Price,† Bartlesville, Okla.

(Tulsa Meeting, October, 1929)

Abstract

Prior to Sept. 1, 1928, there had never been constructed what might be termed a long pipe line with electric-welded field joints. A year later more than 2500 miles of electric-welded lines had been completed which varied in diameter from 6 to 20 in., and in length from 50 to 700 miles. This paper discusses methods used on five lines with a total length of about 750 miles. The welding equipment used for the firing line or rolling welds, was 300-amp. generators driven with six-cylinder gasoline engines, and for the bell-hole or tie-in welds, 200-amp. generators driven by four-cylinder gasoline engines. A welding gang consisted of a foreman, 6 to 12 firing-line welders and 2 to 4 bell-hole welders, a mechanic and a tractor driver.

Coupons about ¼ in. thick were frequently cut from completed welds, which showed a cross-section of the weld and an indication of its size and penetration. For tests of tensile strength complete welds were cut out. The tensile strength of 52 welds cut from 420 miles of 12-in. line averaged 50,870 lb. per square inch.

The following results give a fair average of the number of welds made per man per day: on 157 miles of 8-in. line both firing-line and bell-hole welds averaged 15.3—the firing-line average was 21; on 39 miles of 10-in. line the firing-line average was 19.9; on 50 miles of 6-in. line, with unfavorable weather, the average was 17.7; on 424 miles of 12-in. line most of which was welded during the spring, 10.3, and with good weather the average rose to 13 welds per day. The average time for making a complete weld on 12-in. pipe 0.313 in. thick was found to be 30 min. for the rolling weld and 45 min. for tie-in welds.

A comparison of costs between electric and gas welding shows that the cost of labor for electric welding is 25 per cent. more than gas, generating cost 61 per cent. less than gas, welding wire 40 per cent. less than gas, and supervision and overhead the same. Estimating 50 per cent. annual depreciation on electric welding equipment, and no depreciation

* This paper is available at the office of the Institute as *Technical Publication* No. 251.

† General Manager, Welding Engineering Co.

on generators and gas welding equipment, the final figures show a total saving of 22 per cent. for electric-welded over gas-welded field joints.

DISCUSSION

J. R. Suman,* Houston, Texas.—You say this cost of electric welding is 22 per cent. cheaper than the gas welding. What is the cost of building these lines as compared with screw pipe or Dresser couplings?

H. C. Price.—I have always understood that even acetylene welding is cheaper than Dresser couplings.

J. R. Suman.—I think this paper is an outstanding contribution to welding, which is very important now, not only in the laying of lines, but in the hard surfacing of drilling equipment and other phases of the business.

W. G. Heltzel,† Tulsa, Okla.—During the last three years old methods have given way to new and better methods in the pipe line industry. The outstanding development in this period has been the welding of field joints of oil and gas pipe lines, and more particularly during this year the principal development has been the electrically welded joints. A pioneer in the field of electrically welded pipe line joints is H. C. Price, the author of this paper. My experience has been more particularly with the gas-welded oil line. However, I would like to add some information concerning the gas and electrically welded lines.

One of the faults in the construction of welded lines has been the lack of organization in the field construction crews. I can say that the construction crews for welded lines are not nearly as well organized as the old pipe line crews that were used for laying screwed joints. In the laying of screwed pipe every man had his place in the crew and was carrying on effectively throughout the day. The old pipe line crew would go out in cold weather and lay a great deal more line than can be laid today by either gas or electric welding. In the laying of electrically welded lines it is a common sight to see a good part of the crew idling around while a few welders are working. This lack of organization may be due to the fact that old experienced men who laid pipe lines for years are yielding their places to new and younger men; and it may be that after these new men have had considerable experience we will witness an equal degree of efficiency in crews used for laying welded lines as existed in the crews that laid the screwed line.

It appears that bad weather conditions caused greater delays in the construction of welded lines than was experienced in the laying of short lengths of screwed pipe. Last January our company laid about 400 miles of pipe line loops from points in the Mid-Continent to Chicago, and considerable difficulties were encountered on account of the weather conditions. The crews making the "roll" welds, I refer now to the gas acetylene welds, had finished some distance ahead of the tie-in crews and on January 1, about 8 miles of 200-ft. sections of pipe was strung out along the right of way of each loop in Missouri and Illinois ready to be tied-in to the line.

On January 1 rain began, and continued for two days. The ground became soft and muddy, then the temperature dropped suddenly and for three or four days subzero weather existed. The 200-ft. sections of pipe became tightly frozen to the ground and since flood conditions existed on account of the heavy rainfall for two days before the freeze, the 200-ft. sections were filled with water which froze

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† Sinclair Pipe Line Co.

solid. Freeing the joints from the frozen ground and trying to swab the section free of ice before tying it into the line caused considerable delay. Some of the crews were held up for as much as one-half day, trying to clear the ice out of one of the 200-ft. sections of pipe. With a screwed line, the short sections of 16 or 20-ft. pipe could have been freed easily from the ground and swabbed and tied into the line, and little delay would have been occasioned by the weather conditions.

On this particular job it was a good day's work if 2000 ft. of 8 or 10-in. pipe were tied into the line during the bad weather. At least 3500 or 4000 ft. of screwed pipe would have been laid in the same time.

In very cold weather the welding crews and the pipe-laying crews are not very efficient because so much time intervenes between their activities, and the workmen cannot keep warm. There was a tendency on the part of the men not to come out to lay pipe line on cold days. In the old pipe line crews every man was usually on the job at 7 o'clock in the morning and the pipe line was laid usually, regardless of the weather, and at the end of the day's work they could account for 3000 or 4000 ft. of pipe laid.

During the bad weather as much as 2 hr. was lost trying to start tractors and putting the generators in operation. But offsetting these delays in construction there is the distinct advantage in the welded line—that it is a much better and more reliable job when it is finished.

Reference might be made to 200 miles of 8-in. gas-welded line that were laid about two years ago. This line was tested with oil and not a failure occurred in the whole length of the line, and during a period of two years of operation since the line was built not a failure has occurred. In 400 miles of 8 and 10-in. gas-welded pipe line which were built about a year ago I understand that four failures occurred in the welds. Two of these in the gas welds were due to the rough handling of the pipe when it was lowered into the ditch. Scrapers have been run through the 600 miles referred to, and in no case has a scraper been hung up in these lines by an icicle.

The history of the old screwed line has been full of failures due to the couplings pulling apart or leaks about the couplings. It has been concluded recently that oil leaks along a pipe line account for a high percentage of corrosion failures in the pipe. And it can be expected that the welded line will prove a material benefit in minimizing corrosion failures. It has been observed also that considerable corrosion results from the stressed metal where the tongs were used in laying the line. The welded line will eliminate any such causes of corrosion.

Oil pipe lines often fail in creek crossings and on the river bank where the bank has been washed away in a slide or during a flood period. Some of the pipe line companies have adopted a policy recently of reinforcing all the welds at creek crossings by heavy straps welded along the length of the pipe and across the weld. In river crossings a special river clamp is used over the strap. A piece of 8-in. river pipe, which was made up of two pieces welded together and reinforced with four steel straps, was pulled in sections to destruction. It required 380,000 lb. to pull it apart. The pipe was broken outside the strap. It is evident from the tests that the creek and river crossings should be reenforced with straps that will give each joint sufficient strength to prevent the failures of the weld under forces encountered in creeks and rivers during flood periods.

The author has referred to water tests in his paper. Last year our company completed some 600 miles of pipe line and in no case was water used to make the test. In fact, the lines were laid during the winter, when it would have been impossible to use water tests in the lines which were laid through the states of Illinois and Missouri, since subzero temperature existed. As soon as the lines were completed each section was filled with oil and put up to its test pressure, and in only one weld out of the many that were used to weld up 600 miles of pipe was there a failure. It is the

conclusion of our company that the water test is not necessary for testing gas-welded pipe lines where a reliable welding crew has been used in the construction work.

The author has dealt justly on the question of cost. It is my opinion that the gas-welded line is about 10 per cent. more expensive than the screwed line, taking into consideration the over-all cost of the pipe and the construction. I am sorry that I have not enough information to justify any statement regarding the cost of the electrically welded line as compared to the gas-welded line.

Electric welding has come into considerable use for repairing lines that are filled with oil. From time to time it is necessary to cut out sections of pipe that have been badly corroded and cannot be continued in service. When a large oil pipe line is cut considerable oil must be drained and the pipe line must be taken out of service while the new pipe is being welded back into the line. The draining of the line not only causes high labor costs in providing for a place to drain the oil, but also it costs in the loss of oil that will be absorbed in the ground. Rather than cut the line and put in new pipe it has become the practice of some companies to electrically weld steel patches over the corroded area. In some cases a full joint of pipe is split in half and a section of the pipe line encased with the new joint of pipe which is electrically welded where it is split. This use of electric welding provides an advantage over the gas welding, because it has not been considered safe to use the gas torch for filling up corrosion pits and it cannot be used for welding when the line is loaded with oil.

Instead of stringing the 40-ft. sections of pipe along the right of way, it might be possible to set up central welding stations and weld the 40-ft. sections into lengths as long as 240 ft., then pull these sections out along the right of way with the tractors. As soon as a certain amount of pipe has been welded into 240-ft. sections, the welding station would be moved ahead, possibly another ½ mile, and set up again. The 240-ft. sections could be dragged out for a distance of ¼ mile in each direction from the central welding station. The advantage in such an arrangement is that the welders could be protected and could work during all kinds of weather, and if necessary more than one shift could be used, thus making it possible to weld over a period of 16 hr. a day in case it is desired to speed up the construction. Another advantage would be that the welding equipment could be concentrated in one place instead of being strung out along the line. And it may be possible that this method of welding the line would be cheaper. I would like to ask the author of this paper what he thinks of such an arrangement.

W. V. Vietti,* Big Springs, Texas.—What is the relative cost as between a victaulic coupled line and welded line, and is the victaulic coupled line satisfactory for oil or gas work?

W. G. Heltzel.—I would use a type of coupling on a trunk line that has a long life. Although this coupling is tight at first, it has a rubber gasket which might be subject to deterioration. Certainly the welded line is the best now.

H. C. Price.—Relative to central welding plants: we have welded at the mill two joints into one—two 20-ft. joints into a 40-ft. joint. As to welding the pipe into 240-ft. joints, I can not imagine putting a 240-ft. joint over the ground at present. The first line we welded had 60-ft. joints, which are too long and difficult to get out on the line. To weld in a station at any line is better than welding in the field. It reduces the cost probably 50 per cent. If the idea could be worked out it would effect a great saving.

During the year we have welded 140,000 joints and in that 140,000 joints only 18 leaks were discovered. I think there must have been many that were not dis-

* Petroleum Engineer, Marland Production Co.

covered. That is all that we found—18 leaks under tests. Some of the lines were not tested with water. Oil was put through a 50-mile line in West Texas with no leaks and another 6-in. line with no leaks.

Getting back to costs; I am not trying to get into an argument on acetylene costs. However, it costs at least $10 a day to supply one man with this gas. With one man on electric welding probably 20 gallons of gasoline and 8 quarts of oil are used, approximately $4, against $10 for gas welding.

J. R. Suman.—How does Mr. Heltzel account for the corrosion where there have been leaks of oil in the screw lines?

W. G. Heltzel.—We have not reached any conclusion on this point, but we do know that it causes corrosion.

R. S. Knappen,* Tulsa, Okla.—In corroboration of what Mr. Heltzel has said regarding the external corrosion of pipe by oil in the soil, I can report that the Gulf Pipe Line has had similar experiences. In several cases lines have been in service for 12 to 15 years before corrosion failure. After the failure the pipe was replaced and relaid in oil-soaked clay or sandy clay. In some cases the new pipe has failed within 3 years. We can only account for this accelerated corrosion by the presence of oil in the surrounding material. It is, therefore, our practice to remove all oil-soaked clay or sand and to bury the pipe in fresh uncontaminated material.

* Gypsy Oil Co.

Superhard Metals for Tool Facing*

By Harry J. Morgan,† Los Angeles, Calif.

(Los Angeles Meeting, October, 1929)

Abstract

One of the greatest improvements in drilling equipment has been the development of hard facing metals which are welded by electricity or by acetylene to form a facing which protects the steel of the bit from abrasive wear. The main desirable characteristics of hard facing metals are resistance to abrasive wear, resistance to shock and perfect bond with underlying metal.

Resistance to abrasion offered by various metals shows many anomalies. Compounds containing carbon, silicon and boron are the most important hard substances. Carbon, as diamond, silicon carbide and especially the carbides of iron, chromium and tungsten are the outstanding hard products in common use. Tungsten carbide is probably the most commonly used. It is made in the electric furnace and it is important to get the right amount of carbon and the correct crystalline structure in order to obtain the greatest hardness and greatest resistance to abrasion. It may be obtained in three main divisions: wrought, cast and casehardened.

Insert hard metals are common. The method of application varies, but it is generally welded to the bit, placed in channels or in drilled holes and covered with a hard surfacing metal. Robinson[1] has given a very complete article on the use of inserts. Gregg and Küttner[2] has discussed the metallography of tungsten carbides and given a good bibliography of the subject.

The time and expense of large-scale testing, together with variations in results, led to the development of a laboratory testing machine for determining the abrasive-resisting qualities of different metals. This machine consists of a motor-driven 40-grain, alumina-base corundum wheel, 8 in. dia., rotating at 30 r.p.m. It is run wet and dressed with

* This paper is available at the office of the Institute as *Technical Publication* No. 256.

† Metallurgists, Oil Well Core Drilling Co.

[1] R. R. Robinson: Use of Hard Metal Inserts in Rotary Drilling Bits. *Oil Field Engineering* (May, 1928) **3**, No. 5, 11.

[2] J. L. Gregg and C. W. Küttner: A Metallographic Study of Tungsten Carbide Alloys. *Trans.* A. I. M. E., Inst. Metals Div. (1929) 581.

another wheel between tests. The sample of metal to be tested is placed on the end of a rod that supports a given weight. The amount of wear is measured after a given time under a given load. The results have not been checked closely, but there are enough data to show that there is a direct relation between these results and comparative wear in actual drilling.

DISCUSSION

H. J. Morgan.—The point has been brought up regarding hardness of various facing materials at red heat. We have not been interested in red hardness but have determined the resistance to abrasion at red heat, which is the more important quality for oil-well tools. We have found that the resistance to abrasion of materials containing a high percentage of tungsten does not show a decrease when tests are made at red heat. These experiments were made on the abrasion test machine in a similar manner to the ones already described.

A machine similar to our abrasion-testing machine has been used for testing abrasive resistance of chromium plating.[3]

When hard facing was first applied to oil tools there was some fear that the underlying metal would be adversely affected, but the base metal has not been weakened to any appreciable extent either by use of electric or acetylene processes.

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[3] R. J. Piersol: Effect of Current Density upon Hardness of Electrodeposited Chromium. Amer. Electrochem. Soc. (Sept. 19, 1929).

Deep Sand Development at Santa Fe Springs

By Joseph Jensen,* McDowell Graves,* W. D. Goold* and M. L. Gwin,*
Los Angeles, Calif.

(Los Angeles Meeting, October, 1929)

During the present year the Santa Fe Springs field has proved to be the most important oil field under development in the United States. Its production will exceed that of any other field. Without it, production within the United States would have been almost in even balance with consumption. The field has forced to the fore and compelled, more than any other single factor, serious consideration of the need of conserving the gas resources of the State of California. It has also contributed much to the development of new drilling equipment and important features in petroleum engineering, and has required the development of a new cement for use in deep wells because of high temperatures. It is the only oil field in the country where wells 8000 ft. deep have become so common that they are no longer given special attention.

The field covers a little less than 1400 acres of land. In it 196 producing deep-zone wells have already been drilled since August, 1928, and 224 wells are still drilling. More wells may be drilled. This indicates that probably more than 450 wells will be drilled in the present campaign. In hardly a year's time it has caused the outlay of nearly $50,000,000 for drilling, and within the year 1929 it will have returned practically an equal amount of revenue.

In contrast to conditions during 1923, when this field was once before an important and disturbing factor, the California oil industry has not been forced to refinance to meet the situation presented by such a large production of oil. There has been practically no unit selling and no stock selling, nor any unnecessary development far beyond the limits of the field.

Production is now about 275,000 bbl. per day and gives every promise of remaining at this figure or increasing to nearly 300,000 bbl. Six months from now the field should still be capable of producing more than 200,000 bbl. per day. Obviously, the need for conserving gas that would be blown to the air, incident to the production of so large a volume of oil, represents a problem in conservation deserving of the most serious attention of the oil industry and of the State of California.

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Changes in Equipment

Changes in equipment are the most noticeable feature that attract the visitor in the field. The derrick has now been increased in height to 136 ft. with a base 26 by 26 ft. All parts of it have been increased in size. Crown blocks, travelling blocks and rotary engines all have roller bearings where formerly plain bearings were used.

Mud pumps are now equipped with steel ends capable of withstanding a pressure of 3000 lb. per sq. in. In order to maintain circulation, the various sizes of drill pipe call for circulating pressures as follows: 8-in., 250 lb.; 6-in., 400 to 600 lb.; 4-in., 700 to 800 lb.; 2 to 3-in., 900 to 1200 lb. To start circulation or to cement necessitates an initial pressure of over 1500 lb. The wire-wrapped rubber mud hose has given way to a steel mud hose consisting of lengths of steel pipes and adjustable, flexible joints.

Upset drill pipe is being used more than formerly. Special heat-treated steel drill pipe has been introduced. Long strings of drill pipe now use a safety or releasing joint about 40 ft. above the drill collar. Boilers delivering steam at pressures of 200 lb. have been introduced within the past 10 months, in contrast to 70 and 100-lb. boilers used in 1923. The building of this heavier equipment has been necessary to reach the greater depths and also to save time in coming out of the hole.

The fishtail bit, so popular a few years ago, has been partly replaced by new types. All of these bits use hard facing material so that it is possible to drill for one or two days without coming out to change. Thus it is that wells drilling between 4000 and 5000 ft. have made as much as 225 ft. per day and wells drilling between 7000 and 8000 ft. have made as much as 135 ft. per day.

The casing program used in this field was developed more than 2 years ago in the Ventura Avenue field and has proved adequate for reaching all depths. Twenty-inch stove pipe at 1000 ft. is cemented as a conductor string, and 13⅜-in. casing is cemented at about 4100 ft. at the first water string on top of the Meyer zone. Strings of smaller size are carried down to the lower zones. Some wells now drilling for the Clarke zone expect to set 9-in. casing at depths near 8000 ft. This promises to be possible from a mechanical viewpoint where shut-offs at lesser depths over other oil zones are not made.

Table I.—*Improvements in Drilling Time*

Year	Depth, Feet	Zone	Days	Average Feet per Day	Well, Assoc. Oil Co.
1923	4741	Meyer	115	41.22	Green No. 2
1926	4600	Meyer	77	59.74	Dewenter No. 5
1928	5780	Buckbee	108	53.44	Green No. 3
1929	6826	O'Connell	111	61.49	Dewenter No. 8

Improvements in drilling time, as shown by the records of wells drilled by the Associated Oil Co. in 1923, 1926, 1928 and 1929 are summarized in Table 1.
Before the campaign is over in 1929, it is expected that 8000-ft. wells will be drilled in less than six months' time.

Oil-bearing Zones

Oil-bearing formation has been encountered in the central part of this field almost continuously from 3500 to nearly 8000 ft. Around the edges of the field and approaching close to its crest are prominent edge waters.

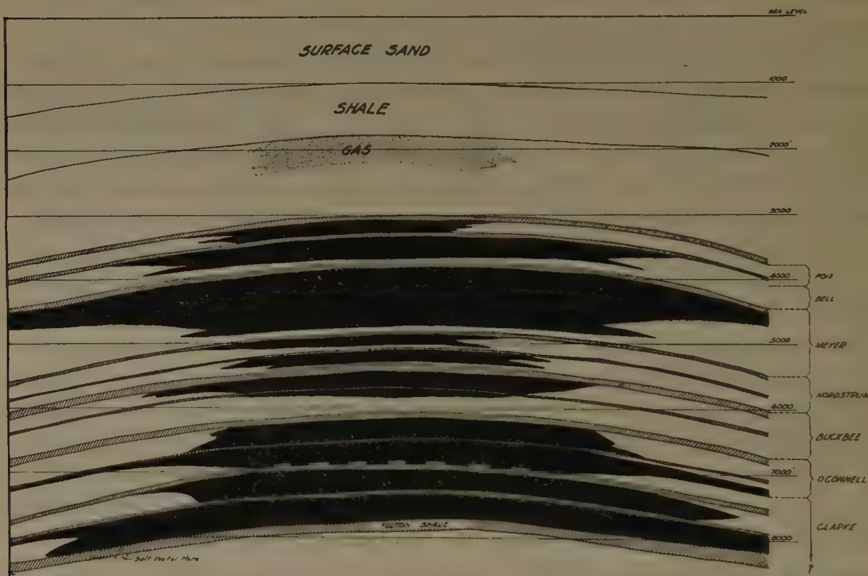

Fig. 1.—Generalized cross-section of Santa Fe Springs field showing gas and oil zones.

They have created particularly difficult problems in petroleum engineering in locating water shut-offs and have compelled the use of many strings of pipe for supplementary shut-offs, to protect the oil zones above the one from which production is being secured. However, the top zone has had no protecting string set above. It has been amply protected by cement and rotary mud. Owing to this fact, the many bodies of productive oil formation limited by intervening edge waters have been named for convenient identification. Fig. 1 shows a cross-section of the field, identifying the various zones. Their names, the depth to which the water shut-off above them is made near the center of the field, and their thickness on top of the structure are given in Table 2.

TABLE 2.—*Gas and Oil Zones, Santa Fe Springs Field*

Zone	Depth Shut-off, Feet	Productive Thickness, Feet
Foix	3500	50 to 100
Bell	3675	100 to 250
Meyer	4050	600
Nordstrum	4900	75 to 200
Buckbee	5600	120 to 300
O'Connell	6300	400 to 700
Clarke	7350	550 to ?

The identification of the zones above the O'Connell is now well established by drilling, but designations relative to the Clark zone are not so definite. Associated Oil Co. Clarke No. 2 was one of the few wells deepened from the Meyer zone for the purpose of prospecting outlying territory. The first oil sand it encountered at great depth was originally called the Upper or First Clarke. Eventually this proved to be part of the Lower O'Connell zone. The second oil sand encountered by it was called the Second or Lower Clarke; the third, the Third Clarke or the Hathaway. In this discussion, the Second Clarke and the Third Clarke are combined under the name of the Clarke zone, since they have now been proved continuous on top of the structure. Like each of the other zones, it derives its name from the well in which oil was first commercially produced.

Beneath all of these zones there is still the possibility of additional oil-bearing formation. An excellent shale body more than 100 ft. thick, as shown on the cross-section as the Fulton shale, has been cored. While water appears to have been encountered beneath this shale in the Fulton wells, it is still possible for a zone of the extent of the Bell or the Buckbee zone to exist on top of the structure. If later found, it would merely be a continuation of the Clarke zone, as this has not yet been fully penetrated on top of the structure.

DEEP DRILLING

Just when prospecting and deep drilling will stop is difficult to forecast. The Meyer zone in 1923 was extensive enough to furnish production for nearly all wells drilled. The Clarke zone gives every promise of being equally extensive. Consequently, the Clarke zone may represent a convenient stopping place for all wells now drilling. Many of these wells are being finished with 4¾-in. water shut-offs, so that they can not be carried deeper. It is therefore anticipated that the Clarke zone will be the termination of the present Santa Fe Springs drilling campaign.

There appears to be no limit either to human curiosity or to the depth to which wells can be drilled, so this statement is not to be taken as a

promise of what may follow in the Santa Fe Springs field. Formations thus far identified are Pliocene and Miocene. An appreciable thickness of Miocene formation has been proved productive successively in the Richfield, Huntington Beach townsite, Long Beach and Seal Beach fields. A portion, if not all, of the Clarke zone is in the Miocene. While the geology does not justify the expectation of additional oil sands (other than some reasonable extension below the Fulton shale), as the Miocene has not been fully tested by deep drilling in the above-named fields, the future of deeper drilling at Santa Fe Springs will be much the same as that in these other fields.

The Nordstrum, Buckbee and O'Connell zones were developed from the center toward the edge of the field. Development of the Clarke zone is proceeding in the opposite way. Therefore it will be more rapid, so that this factor will tend to balance the time taken in drilling such deep wells.

Various Problems

Fortunately, the shale bodies overlying the oil zones have been so persistent throughout the field that the selection of proper cementing points has been remarkably uniform, in spite of crooked holes that are so prevalent because of the depths being drilled. Continuous coring for as much as 3000 ft. in outlying wells has been necessary. Practically all wells have cored several hundred feet of formation even in the center of the field.

Such problems were solved with relative ease, but following the discovery of the Clarke zone, a new difficulty presented itself. The first wells to reach this zone were located on the outer rim of the field and beyond the limits of the new zones. Successful water shut-offs were not secured. It is now known that much of this difficulty was simply due to edge water in sands that could not be made productive. At the time, however, the great depths of the wells caused an investigation as to well temperatures. These proved to vary from 190° to 212° F. After these temperatures were discovered, laboratory tests proved that most cements when mixed and allowed to set at such temperatures failed to show any uniformity or regularity in performance.

As a result of these tests, the Pacific Portland Cement Co. attacked the problem presented by high temperatures and solved it by manufacturing a new "high-temperature" cement, designed to set and give a maximum strength at these high temperatures. The cement has been in use for several months and gives every promise of meeting the difficulty presented by high temperatures.

Later developments proved, however, that the temperature was not entirely responsible for the water shut-off failures in many of these early Clarke zone wells, but rather edge-water conditions. Subsequently,

most of the commercial oil-well cements were used successfully in securing shut-offs where the cementing operation was conducted with despatch and without loss of time. Difficulties arose only in those instances where the cementing operation was so delayed that the high temperature caused the cement to take its initial set before it had been put in place. The time in which the new high-temperature cement sets in the well is nearly twice as great as that of ordinary oil-well cements. Consequently, the operator using high-temperature cement has over 1½ hr. in which to get his cement in place after mixing, whereas the operator using ordinary oil-well cement may have difficulty with his cementing job, unless the cement is in place in 45 to 55 min. after it is mixed.

The problem of satisfactorily locating water in an uncased hole gives promise of being solved. In several wells fully 8000 ft. deep and having from 200 to 400 ft. of open hole, it has been possible to introduce an electrolyte through tubing, or drill pipe. The tubing is then pulled up inside the water string or the drill pipe is removed, and electrodes are run through the tubing or the water string. Fluid is bailed in sufficient amount to cause the salt water to enter the hole. It dilutes the electrolyte so that the voltmeter readings are greatly reduced. While the use of electrolytes in locating water is not entirely new, the locating of water in uncased holes has heretofore been impossible except by plugging in stages.

Production from the Different Zones

Data on the various zones at the present time are shown in Table 3.

Table 3.—*Production from Various Zones*

Zone	Total Wells Produced from Zone at Time of Peak Production	Past Producers	Present Producers	Production of Sept. 24, 1929, Bbl.
Meyer	296	79	217[a]	26,238[a]
Nordstrum	40	19	21	13,836
Buckbee	100	59	41	22,330
O'Connell	128	29	99	130,934
Clarke	36	1	35	80,366

[a] Includes some Foix and Bell zone wells.

The many producers that have been abandoned in the Buckbee zone to produce from the O'Connell zone indicate that a similar number of wells will be abandoned in the O'Connell zone within the next few months to secure production from the Clarke zone. The abandonment of most of these wells has been forced by the invasion of edge water, which practically killed the production of oil and gas. This invasion of edge water in the O'Connell zone has begun, as evidenced by the score

of former O'Connell zone producers. The O'Connell zone has ceased to be the objective for which most of the wells in the field are now being drilled. Of the 224 active drilling wells, at least 150 are known to be planned as Clarke zone wells. The remaining 74 wells may produce from the O'Connell zone for a time, but a portion of them will be carried into the Clarke zone.

An interesting feature brought out by subsurface contour maps is that the loci of the crest of the zone structures lie within a belt about

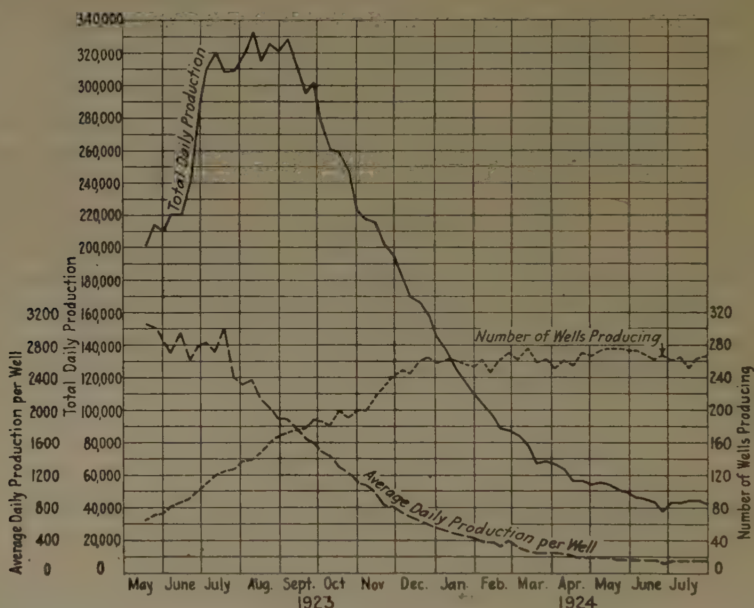

FIG. 2.—PRODUCTION CURVES, MEYER ZONE, SANTA FE SPRINGS.

500 ft. wide. The crests of the Buckbee and O'Connell zones seem to be fairly vertically superimposed over the crest of each underlying zone. The crest of the Meyer zone is distinctly south of the crests of the underlying zone structures and is also much sharper. The top closing contours illustrate this southward displacement. A study of the various contour maps shows that the closure on the Meyer zone is 50 to 100 ft. more than the closure on each of the underlying zones. This additional closure resulted in the top of the Meyer zone being shoved south, as compared with the underlying zones.

Production data of the different zones are graphically shown in Figs. 2–6. The most interesting relationship brought out by them is that between average initial production per well and average daily production of all wells producing in each zone. Owing to the fact that edge-water wells and small producers were promptly abandoned, the wells that

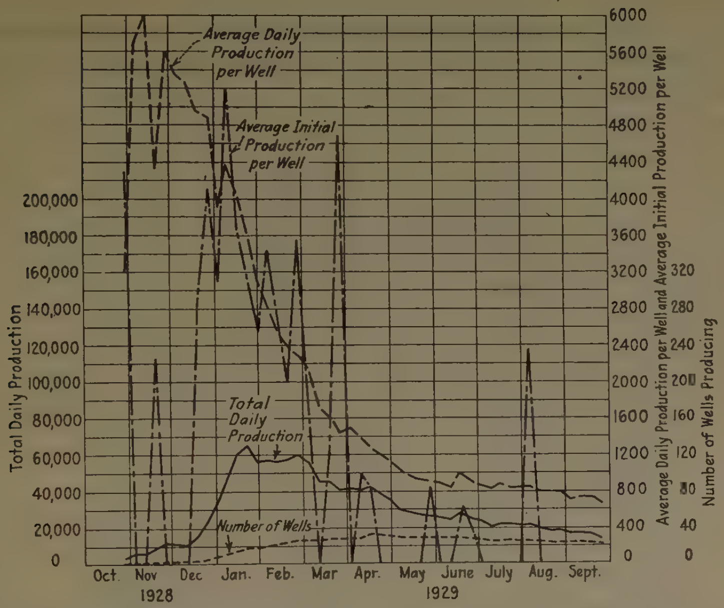

FIG. 3.—PRODUCTION CURVES, NORDSTRUM ZONE, SANTA FE SPRINGS.

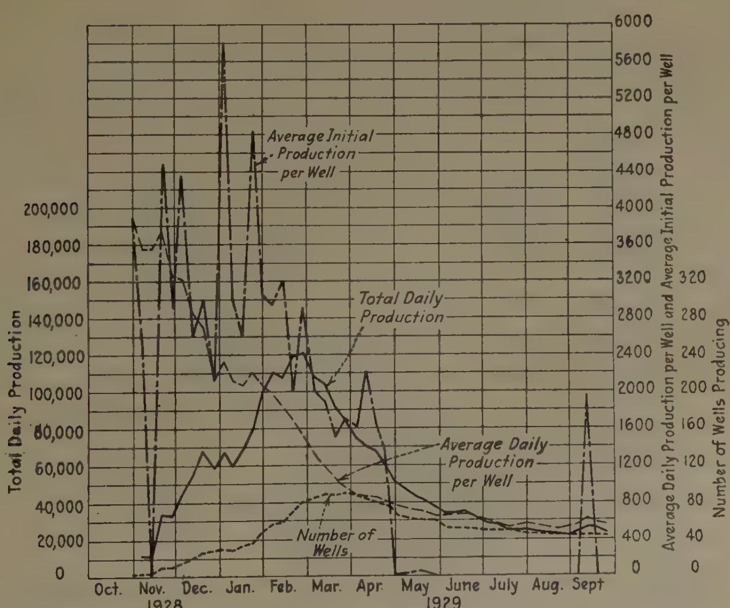

FIG 4.—PRODUCTION CURVES, BUCKBEE ZONE, SANTA FE SPRINGS.

contributed to the average daily production were strong representative producers. The new wells brought in each week were scattered throughout the field, so that they were probably about as representative as the producing wells.

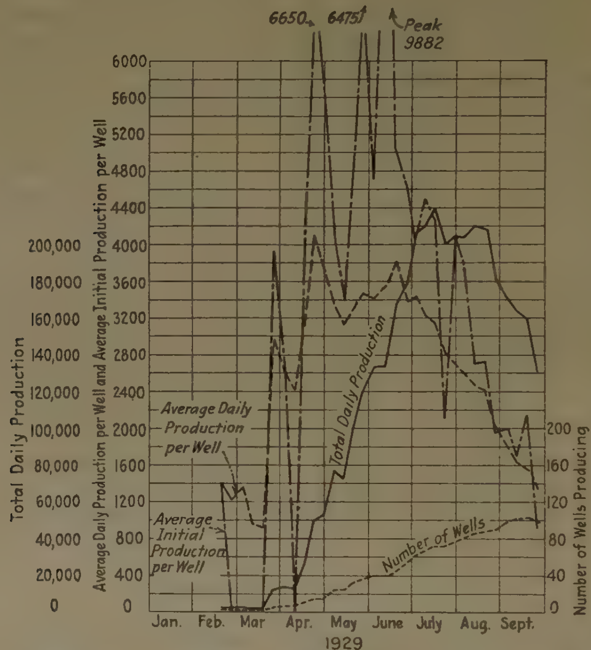

FIG. 5.—PRODUCTION CURVES, O'CONNELL ZONE, SANTA FE SPRINGS.

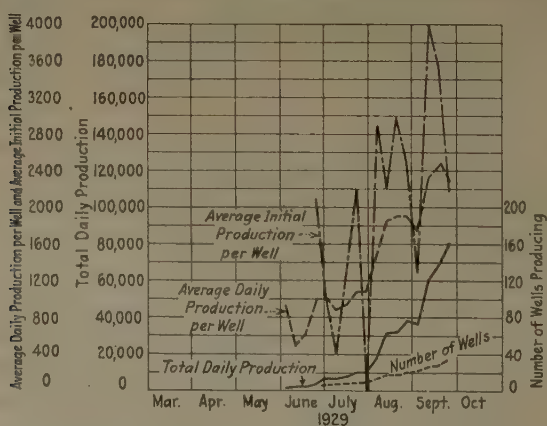

FIG. 6.—PRODUCTION CURVES, CLARKE ZONE, SANTA FE SPRINGS.

After each zone has definitely passed its peak of production, the decline in initial production and daily production parallel each other remarkably. It is surprising that the initial production of the new wells

is not much larger than the average production of the wells in the zone. This tends to indicate that where zones are drilled simultaneously, such as is now common in a field of many ownerships, the oil pool becomes very much of a unit from which production is taken fairly uniformly by all producing wells. This indicates that after a zone has been drilled up, there is little to be gained by hastening the recovery of oil and gas beyond the market needs of the community being served. The advantage of securing the flush production is largely gained in the early life of the zone, but once the zone is drilled up, this advantage disappears rapidly. Prudent conservation of resources, therefore, justifies retaining the gas in the ground with the oil until the gas can be used by the community, rather than permitting it to be blown in the air.

The impression is so widespread that Santa Fe Springs is essentially a town-lot field that it is worth while to call attention to the fact that the abandonment of wells in one zone to permit their use in the development of a deeper zone has resulted in the acreage per producing well being practically as satisfactory as that in fields of larger ownership than the town-lot area of Santa Fe Springs. Unquestionably, in these zones there is still much oil to be recovered that will be recovered during 1930. These zones will again be developed by drilling. This was the experience in 1924, following the exploitation of the Meyer zone. In August, 1923, the number of Bell zone producers was reduced to 26; by October of 1924 it had increased to 79.

The production curves also bring out the fact that the increase in the average daily production per well is rapid until a peak is reached. This is followed by a sustained average and then a less abrupt decline, until the production of the well falls to between 1000 and 500 bbl. per day. Thereafter the decline is gradual. Meyer zone wells declined until they averaged less than 200 bbl. per day. That was before the day of the gas-lift. It is highly probable that the gas-lift will maintain the average production of the wells in the different zones at somewhere between 300 and 500 bbl. per day.

The total daily production of the various zones and the total production of the field are shown in Fig. 7. This shows that the various zones had peak productions as follows:

Zone	Date	Peak Production, Bbl. per Day
Nordstrum	Jan. 22, 1929	63,647
Buckbee	Feb. 26, 1929	122,325
O'Connell	July 16, 1929	220,592

It is surprising that the peak production of the field failed to coincide with peak production from any of these zones. The peak production

of the field was established on August 13 at 309,338 bbl. This peak was due to new flush production secured from the Clarke zone after the O'Connell zone had passed its peak. Each of these zone curves has a rather flat top, followed by an abrupt drop.

Fig. 7 indicates clearly that the Foix, Bell, Meyer, Nordstrom and Buckbee zones have reached what may be termed fairly settled production. The O'Connell zone may be expected to continue its rapid decline until a production of less than 100,000 bbl. is had, but by the time it

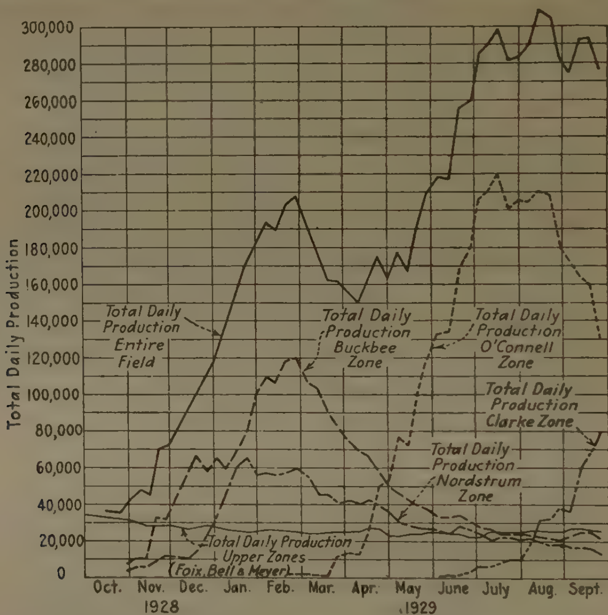

Fig. 7.—Production curves, field totals, Santa Fe Springs.

reaches 50,000 to 60,000 bbl. its production should be settled. By the end of the present year, these various sources of production will, therefore, contribute the following amounts of oil: Upper zones, 25,000; Nordstrom zone, 10,000; Buckbee zone, 20,000; O'Connell zone, 50,000; total, 105,000 barrels.

An examination of the trend of the total daily production of the Clarke zone indicates that it is rising almost as steeply as the curve of flush production of the other zones rose earlier in the year. By the end of the year it might rise to 100,000 or 150,000 bbl. per day. Hence the production of this field could easily amount to 200,000 and might possibly be above 250,000 bbl. at the end of the year.

The production of the field in gas and oil during the present year in monthly totals and daily averages, also the gas-oil ratio for the field, are given in Table 4.

Nearly three-fourths of the gas now being produced is blown into the air. The need of conserving it has been appreciated by the State

TABLE 4.—*Oil-gas Ratio of Santa Fe Springs during* 1929

Month	Total Oil, Bbl.	Daily Average Oil, Bbl.	Total Gas, M. Cu. Ft.	Gas-oil Ratio
January	4,759,671	153,538	9,524,489	2,001
February	5,300,380	189,299	12,673,731	2,391
March	5,275,300	170,171	13,813,468	2,618
April	4,749,940	158,331	10,261,794	2,160
May	5,629,580	181,600	10,110,604	1,795
June	7,123,985	237,466	13,360,911	1,875
July	8,134,548	262,405	18,671,698	2,295
August	8,726,533	281,501	20,872,201	2,391

of California. An injunction has been sought so that it may be conserved for beneficial use. As the field still has a long life ahead and the gas can assist in recovering additional oil from the Meyer zone, as well as the deep zones, a conserving of gas will probably result in an added oil recovery from the field.

Research

Chapter VIII. Oil Recovery

Recent Studies of the Recovery of Oil from Sands*

By Joseph Chalmers,† Bartlesville, Okla.

(New York Meeting, February, 1930)

The Petroleum Experiment Station of the U. S. Bureau of Mines at Bartlesville, Okla., has for the past three and a half years maintained a laboratory with the necessary personnel for conducting research on methods of increasing the recovery of oil. Some of the preliminary problems encountered in starting this work, with the data obtained, were discussed in A. I. M. E. *Technical Publication* No. 144, "Oil Recovery Investigations of the Petroleum Experiment Station of the U. S. Bureau of Mines," which was presented at the October meeting of the Institute at Tulsa, Okla., in 1928.

Scope of Paper

The following discussion gives some of the results of the more recent work at the Oil Recovery Laboratory. These experiments were conducted to obtain laboratory data pertaining to the relative merits or efficiencies of various pressure media in the recovery of oil from a sand reservoir. Two general types of experiments were conducted. In one the various pressure media were passed through an artificial body of sand partly saturated with oil at a constant input pressure; in the other the pressure media were passed through the body of sand partly saturated with oil at a constant volume rate. No attempt will be made to discuss the ramifications of economic problems which enter into the choice of a pressure medium.

Apparatus and Materials

The two 6-in. by 6-ft. flow tubes described in *Technical Publication* 144 were used in these experiments. They consist of 6-ft. sections of 6-in. casing with a blind flange at each end. There are three 1-in. well openings in each tube, spaced 2 ft. 4 in. apart, the end wells being

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† Associate Petroleum Engineer, U. S. Bureau of Mines.

8 in. from the faces of the blind flanges. Three ¼-in. openings, similarly spaced, and located at 90° to the 1-in. openings, serve for pressure-gage connections. The 1-in. well openings are equipped with miniature wells extending to the opposite wall of the tube and having perforated screen pipe for the bottom 3 in. or the bottom half of the sand body. Only the end wells and the end pressure-gage connections were used. One well was used for gas injection and the other as the producing well.

A fine-grained, white, quartz sand from an outcrop of the Wilcox formation, was packed tightly into the flow tubes to form the sand reservoir for the oil. The porosity of the sand under these conditions is about 30 per cent. Oil from the Bartlesville sand, of 33° A. P. I. gravity and a Saybolt Universal viscosity of 60 sec. at 70° F., was used.

The various pressure media were (1) propane, (2) a mixture of propane and dry gas, (3) air, (4) dry gas, and (5) helium. The propane-dry gas mixture consisted of 37.26 per cent. propane and 62.74 per cent. dry gas. This mixture gave a gas of the same density as air. Bartlesville city gas served for the dry gas. As the gas from the city mains changes in composition from time to time, a sufficient quantity of the gas to complete the series of experiments was stored in a high-pressure gas storage system provided for that purpose. An ample supply of dry gas of constant quality was thus assured. A sample of this gas gave the analysis: carbon dioxide, 1.8; illuminants, 0; oxygen, 0.48; butane plus, 1.67; methane, 75.22; ethane, 6.95; propane, 3.84; nitrogen, 10.04; total, 100 per cent.

The solubilities of the above pressure media in the Bartlesville crude used were:

Pressure Medium, Cu. Ft. per Bbl.	Pressure 50 Lb. Gage	100 Lb. Gage
Helium	0.7	1.4
Air	3.0	6.0
Dry gas	9.5	19.0
Propane-dry gas mixture	24.8	49.6
Propane	407.0	2262.4

Procedure

All experiments were conducted in a constant temperature bath at a temperature of 70° F., and each gas injection run was started with the flow tube or sand reservoir partly depleted of its oil by "natural flow." The state of depletion of the sand, prior to the pressure drive, was the same in each case. This was accomplished by charging the flow tubes with oil saturated with dry gas at 200 lb. pressure and at 70° F. The tubes were then partly depleted by a so-called expulsion run, in which the expansive force of the dissolved gas was allowed to expel what

oil it would. The degree of depletion brought about in this manner is surprisingly uniform. It amounts to approximately 23.3 per cent. Under ordinary circumstances this does not vary over 0.5 per cent.

With the flow tubes depleted 23.3 per cent., the gas injection runs were started. For the runs in which a constant input pressure was maintained, a gas cylinder of calibrated volume was connected to the input well of the flow tube through a pressure regulator. For the runs in which a constant input volume rate was maintained, a small orifice was used in conjunction with the pressure regulator. Except for propane, the variable volume input rate of the first type of run (in which the flow tube input pressure was held at 25 lb.) was determined by the pressure drop on the calibrated storage cylinder. Propane, having a vapor pressure of only 120 lb. per sq. in. at 70° F., was in a liquid state in the storage cylinder. The volume input of propane was measured by an orifice.

The constant input volume rate of the second type of run was maintained by means of critical flow through the small orifice. The volume rate in these runs was 0.178 cu. ft. per min. Due to the variation of the flow tube input pressure or the downstream pressure of the orifice during these runs, an orifice had to be chosen for each pressure medium which would produce critical flow conditions through the entire range of pressures on the flow tube during each run.

Results

In the first type of experiment, in which the pressure media were injected into the flow tube, or sand reservoir partly filled with oil at a constant pressure input of 25 lb. per sq. in., the data obtained showed that the more soluble gases passed through the oil sand more freely than the less soluble gases. In other words, the greatest rate, of gas injection at a constant pressure input of 25 lb. was obtained with propane and the lowest rate with air. The initial volume input rates were: propane, 1.42 cu. ft. per 5 min. interval; propane-dry gas mixture, 0.83 cu. ft.; dry gas, 0.54 cu. ft.; and air, 0.23 cu. ft. per 5-min. interval. These rates declined to 0.70, 0.57, 0.46 and 0.21 cu. ft., respectively, by the third 5-min. interval, after which they increased as gas injection continued at the constant pressure input. At the end of 3 hrs. the rates were: propane, 4.04 cu. ft.; propane-dry gas mixture, 3.10 cu. ft.; dry gas, 2.40 cu. ft.; and air, 1.60 cu. ft. per 5-min. interval. Although a portion of the differences in gas injection rates for the various pressure media at the end of 3 hr. may be accounted for by the difference in percentage depletion of the sand, it does not account for the entire difference in rates, nor does it account for the difference in the initial rates when the state of depletion of the sand was the same in each case. The difference in injection rates for the various pressure media may, however, be explained

as due to the difference in their solubilities. A portion of the more soluble gases traveled at least part of the distance through the sand as gas in solution in the oil. As the oil with gas in solution moved toward the producing well, and hence toward lower pressures, part of the dissolved gas expanded from solution. This was evidenced by smaller pressure drops from input well to within a few inches of the producing well in the case of the more soluble gases. The pressure drops varied inversely as the solubilities of the pressure media in the oil.

The greater rates at which the soluble gases passed through the sand produced higher rates of recovery. Viewed from the standpoint of the gas-oil ratios involved, this did not always mean the most efficient operation, as is shown in Table 1. Propane gave the lowest total gas-oil ratio. The propane-dry gas mixture and air gave about equal total gas-oil ratios which were next in magnitude. Dry gas gave the highest total gas-oil ratio. The pressure media may then be named in the order of their specific gravities to designate their relative efficiencies in the recovery of oil from sands. Although the propane-dry gas mixture was considerably more soluble than air in the oil used, its efficiency in the propulsion of oil through the sand was not very different by this method of analysis. Dry gas, although more soluble than air, was somewhat less efficient.

Table 1.—*Relative Recoveries of Oil by Gas Drive Maintaining a Constant Input Pressure of* 25 *Lb. Propane, Propane-dry Gas Mixture, Air and Dry Gas;* 1/16*-in. Flow Nipple*

Pressure Medium	Oil Recovered by Expulsion Run, Per Cent.	Time Interval for Gas-oil Ratio to Reach 11,200 Cu. Ft. per Bbl. by Gas Injection, Min.	Oil Recovered by Gas Injection to Limit in Gas-oil Ratio of 11,200 Cu. Ft. per Bbl., Per Cent.	Total Gas-oil Ratio for Gas Injection to Assumed Limit	Time Interval to Recover Additional 22 Per Cent. of Oil by Gas Injection, Min.	Total Gas-oil Ratio for Gas Injection	Work Done to Recover 22 Per Cent. of Oil by Gas Injection, Ft.-lb.
Propane	23.3	102	27.3	2,106	62	1,067	21,124
Propane—Dry Gas Mixture	23.2	142	21.6	2,517	146	2,610	54,302
Air	23.2	190	22.0	2,577	190	2,577	60,959
Dry Gas	23.4	156	21.1	2,768	168	3,060	66,167

The work done by the four pressure media used in recovering 22 per cent. of the original content of the sand in excess of the 23.3 per cent. recovered by "natural flow" is also shown in Table 1. In the author's opinion, this gives a better picture of the true relationship between the pressure media in connection with their efficiencies in the recovery of oil from sands. The greater solubility of the propane-dry gas mixture over air and the resulting decrease in energy expended is brought out. Again,

although dry gas is more soluble than air, dry gas was less efficient. This was due to the excessive volume of gas required, which more than compensated for the lower pressure differential through the sand.

The pertinent data for the second mentioned type of experiment, in which the pressure media were injected at a constant volume rate, are given in Table 2. These data afford much the same interpretation as was given for the first type of experiment. Due to the persistent indication that the densities of the pressure media might have some bearing upon their efficiencies in recovering oil by gas injection, helium was tried, not because there was any likelihood of helium being used as a pressure medium but because it was almost insoluble in the oil used and had a specific gravity much lower than air. The result shows that the density of a gas does enhance its value as a pressure medium, but only slightly.

TABLE 2.—*Relative Recoveries of Oil by Gas Injection at Constant Input Volume of* 0.178 *Cu. Ft. per Min. Propane, Propane-dry Gas Mixture, Air, Helium and Dry Gas; 1/16-in. Flow Nipple*

Pressure Medium	Oil Recovered by Expulsion Run, Per Cent.	Time Interval to Recover Additional 22 Per Cent. of Oil by Gas Injection, Min.	Total Volume of Gas Required to Recover 22 Per Cent. of Oil by Gas Injection, Cu. Ft.	Mean Flow Tube Pressures, Lb. Gage		Work Done to Recover 22 Per Cent. of Oil by Gas Injection, Ft.-lb.	Total Gas-oil Ratio for Gas Injection
				Input	Output		
Propane	23.2	96	17.088	17.78	3.13	20,400	1,181
Propane—Dry Gas Mixture	23.2	132	23.496	19.97	3.04	32,800	1,624
Air	23.4	130	23.140	25.55	3.10	38,800	1,600
Helium	23.4	138	24.564	23.54	2.75	39,700	1,698
Dry Gas	23.5	169	30.082	18.97	2.55	41,900	2,080

There are physical and chemical properties of gases or combinations of these properties other than those discussed which have their effect upon the efficiency of a gas when used as a pressure medium. Perhaps the viscosity of the gas or the interfacial tension between the gas and the oil plays some part. It is difficult to decide the degrees of importance of the various properties in the recovery of oil from sands when almost all of these properties change with each gas. Unfortunately, these experiments give only the cumulative effect of all the variables.

A comparison of the data contained in Tables 1 and 2 brings out the importance of volumetric control of the pressure media in repressuring operations. The data in Table 1 represent the results which might be expected without volume control of the injected gas, whereas the data in Table 2 represent the results with volume control. The second type of

operation is much more efficient both as to the gas-oil ratios involved and the work done to recover a given quantity of oil.

The two general types of experiments described and discussed were performed using a 1⁄16-in. flow nipple in the producing well. Other experiments were performed using a 1⁄32-in. flow nipple. The only difference in the two sets of experimental data was in the amount of oil recovered for a given volume of gas used or for a given amount of work done. The difference was most pronounced when propane was used and least noticeable when air was used. As propane is most soluble in the oil, it caused the greatest amount of latent energy to be stored in the oil in the form of dissolved gas, due to the increased back-pressure on the producing well. This stored energy was dissipated after the oil passed the flow nipple, and did not aid in the work of moving the oil to the producing well other than by effecting a decrease in the viscosity of the oil. Less oil was recovered under the slightly increased back-pressure.

Summary of Conclusions

The following conclusions may be drawn from the data presented:

1. The density of a pressure medium has some effect upon the recovery of oil with a "gas drive." This is true because of the greater kinetic energy available in a denser medium.

2. The experiments with constant input pressure and constant input volume showed the importance of proper control in the effect on the gas-oil ratios for the two conditions of gas injection. The total gas-oil ratios for equal recoveries of oil were much lower when a constant input volume was maintained on the flow tube than when a constant input pressure was maintained.

3. The solubility of the pressure medium in the oil must also be considered. The fact that the more soluble pressure media may be injected into an oil-saturated sand at lower pressures than the less soluble pressure media is not so important when it is remembered that the cost of compressing gas from atmospheric pressure to 100 lb. per sq. in. is approximately two-thirds of the cost of compressing it to 1000 lb. The most important feature is to force as much gas into solution in the oil as practicable and then control the pressure gradient to the producing wells. The dissolved gas should expand from solution in such a manner that it will do its full quota of work by the time it reaches the producing well. Gas which goes into solution too freely does not have the potential energy to expand from solution when pressures are reduced. The desired solubility of a pressure medium depends upon the pressures existing in the sand reservoir. It is true that dissolved gas will reduce the viscosity of the oil and probably cause the oil to move more freely, but in the author's opinion, which is based upon the experiments so far conducted, the benefits derived from a reduction of the viscosity of the oil are not of

more importance than those which accrue through a complete utilization of the energy in the gas.

DISCUSSION

H. H. HILL,* New York, N. Y.—To sum this up, you found the propane is a little more efficient as an expulsive agent than dry gas or air, or a mixture of dry gas and propane, but the difference is not as much as many of us have been led to believe in the past.

J. CHALMERS.—Yes, if the more soluble gases are used under conditions which preclude their expansion from solution. A point might be brought up in this connection. Propane and butane, by-products of gasoline plants, have been injected into the oil sand in the Burbank field. In one case they were being pumped into the injection well as a liquid. Little or no increase in production of oil was noticed.

I think the explanation is that the rock pressure was sufficient to maintain the propane and butane in solution in the oil. There being no expansion of gas from solution, one could hardly expect an increase in production. There may be some benefit derived from the reduction of the viscosity of an oil by dissolved gas in promoting its mobility, but it seems that greater benefits accrue by taking advantage of the energy stored in the dissolved gas by allowing that gas to expand from solution.

H. H. HILL.—On the basis of these tests, would it be advisable to extract the gasoline from the gas before it is returned to the sand?

J. CHALMERS.—No, if a reduction in the viscosity of the oil is as important as other investigators have led us to believe.

H. H. HILL.—It is important to know whether it is advisable, in repressuring, to extract the gasoline and introduce the dry gas into the sand, or simply inject the gas without taking out the gasoline.

J. CHALMERS.—It seems to me that a great deal depends upon how "wild" the gasoline is. The "wilder" it is, the more useful it will be in repressuring. A pressure medium should possess sufficient energy when dissolved in the oil to expand from solution as it moves toward the producing wells.

There probably is a critical point in the relationship between the viscosity and surface tension of an oil and its recoverability. That critical point would be the point at which gas slippage due to the attending reduction in the surface tension of an oil would more than offset the benefit to be derived from a further reduction of the viscosity of the oil. The pressure medium should be of such composition as to be dissolved in the oil under the injection pressure. Then, in expanding from solution as it moves toward the producing wells and areas of lower pressure, the surface tension of the oil should be sufficient to retain the gas in the occluded state in order to more effectively fill the interstices of the sand with oil thereby giving the gas drive something to work against, and eliminating excessive slippage.

L. S. PANYITY, Bradford, Pa.—There is a new method which seems to be coming into use, whereby the exhaust gases of gasoline engines that are used for power are being returned into the wells and used in places where gasoline is being recovered, and the gas used over again. What possible effect, good or bad, may result from that?

J. CHALMERS.—That is, the burnt gases? I do not know of any bad effect other than the fact that exhaust gases from compressor engines are rather corrosive.

* Petroleum Engineer, Standard Oil Development Co.

Law of Flow for the Passage of a Gas-free Liquid through a Spherical-grain Sand*

By William Schriever,† Norman, Okla.

(New York Meeting, February, 1930)

The flow of a gas-free liquid through a spherical-grain sand has been investigated by Slichter.[1] By theoretical considerations involving a rather large number of approximations he arrives at the following flow-formula:

$$V = \frac{CPd^2At}{NLB(1 - m)}$$

where V is the volume of liquid delivered in time t through a cylindrical column of sand of length L and cross-sectional area A by a pressure-drop P when the sand grains of diameter d are packed to a porosity m and the coefficient of viscosity of the liquid is n. C and B are constants which were determined from geometrical relations; B was in reality a function of m. Values of $B(1 - m)$ for various values of m were given in a table.

In the same Annual Report of the U. S. Geological Survey, King[2] reported the results of his experiments on the flow of water through porous media. He found that there was a departure of about 86 per cent. from a linear relationship between rate of flow and pressure, for a specimen of Dunnville sandstone for pressure drops not exceeding 60 cm. of mercury. The specimen was approximately 4 cm. in diameter and 5.1 cm. in length. Over the same range of pressure he found a departure of 45 per cent. for a specimen of Madison sandstone. For unconsolidated sands he found departures as great as 49 per cent. for pressure drops of 70 cm. of mercury; for pressure drops not exceeding a few inches of water he obtained a close approximation to a linear relation. He also investi-

* This paper contains results obtained in an investigation on The Effect of Natural Gas upon the Viscosity, Surface Tension, Adhesion and General Extractability of Petroleum of Various Types, listed as Project No. 33 of American Petroleum Institute Research. Financial assistance in this work has been received from a research fund of the American Petroleum Institute donated by John D. Rockefeller. This fund is being administered by the Institute with the cooperation of the Central Petroleum Committee of the National Research Council. Prof. H. C. George is Director of Project No. 33.

† American Petroleum Institute Research Fellow and Professor of Physics, University of Oklahoma.

[1] C. S. Slichter: Laws of Rectilinear Flow through a Soil. Nineteenth Annual Report, Geol. Surv. (1897–98) 301.

[2] H. F. King: Principles and Conditions of the Movements of Ground Water. Nineteenth Annual Report, Geol. Surv. (1897–98) 67.

gated the flow through wire gauze, perforated brass disks and other porous media, and in only a few cases did he find an approach to a straight-line relation.

With sieved sand he found, in some cases, a fairly good approximation to the linear relation between pressure drop and rate of flow. He forced air through the sand and computed the effective diameter for the sand grains by using Slichter's flow formula. He then compared the observed rate of flow of water through the sand with the rate predicted by Slichter's formula in which was used the effective grain size obtained by the air-flow measurements. In conclusion he remarks,[3] "The failure to conform with the law amounts to as much as 10 per cent. too rapid to 49 per cent. too slow; while the closest agreement is found in sample No. 44 where the departures vary from a little more than 1 per cent. too slow to 1.5 per cent. too fast . . . It would appear, therefore, that Poiseuille's law for sands and other porous media holds only within very much narrower limits than has been found in capillary tubes."

Since there is no "Poiseuille's law for sands," he evidently meant that the linear relation between pressure drop and rate of flow does not hold. His grain-diameter measurements, which were made by use of air and Slichter's formula, are certainly open to question since the formula, if it holds at all, holds only for fluids which suffer a negligible compression for the pressures employed.

Purpose of Investigation

Since the writer was primarily interested in American Petroleum Institute Project No. 33 as first proposed, which involved the flow of oils through sands, and since the available theoretical and experimental evidence were in conflict, it was deemed necessary first to determine empirically a flow formula for the passage of a gas-free oil through a packed spherical-grain sand.

Apparatus

A schematic diagram of the apparatus is shown in Fig. 1. The spherical-grain sand (glass spheres) was packed in the flow tube which was approximately 5 cm. in diameter and long enough to hold a sand column 24 cm. in length. The oil (nujol) flowed from an oil reservoir having a capacity of 5 l., through a large heating coil and into the flow tube. Pressure was applied to the oil by means of compressed air which was supplied by a tire pump through a 40-gal. air tank. The pressures were measured with an open mercury manometer. The coefficient of viscosity of the oil was determined with a viscometer which also served to check the constancy of the viscosity from time to time during the progress of the experimental work. The heating coil, viscometer and flow

[3] *Loc. cit.* 241.

tube were all contained in a constant-temperature bath, the temperature being that of boiling water (maximum variation 98.5° to 99.4° C.). The quantities of oil delivered were measured by weighing on an equal-arm balance, and the times of flow were determined with a stop-watch. The sands were prepared by carefully sieving crystal frosting with new Tyler sieves.

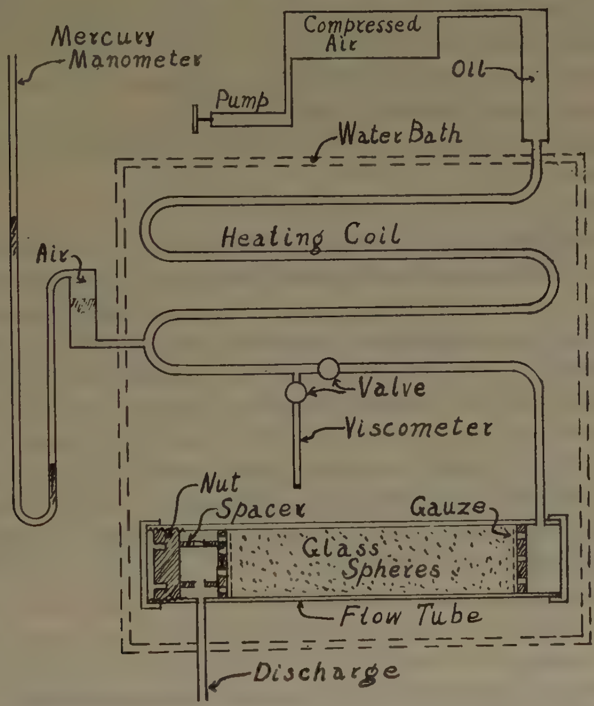

FIG. 1.—APPARATUS FOR DETERMINATION OF LAW OF FLOW FOR PASSAGE OF GAS-FREE LIQUID THROUGH A SPHERICAL-GRAIN SAND.

The density of each sand was determined by immersing a known mass of the sand in water contained in a calibrated burette and reading the increase in volume after all air bubbles had been removed.

The average diameter of the spheres of each sand was calculated from the density and the average mass per sphere, the latter being determined by weighing on a sensitive balance 1000 spheres which had been counted and recounted.

The cross-sectional area of the flow tube was obtained by noting the rise in the surface of water, when the tube was vertical, for known volumes of water. These measurements also revealed the constancy of the cross-sectional area of the tube.

The volume occupied by a sand column was calculated from its length and the cross-sectional area of the tube. The former was obtained from measurements of three lengths: first, the length from the surface of the

gauze near the high-pressure end of the tube to the low-pressure end of the tube; second, the combined length of the nut, spacer, and gauze-covered plate near the low-pressure end; and third, the distance from the outside surface of the nut to the low-pressure end of the tube.

The porosity of the sand was then calculated from the volume V occupied by the sand and the volume v occupied by all the spheres, the defining equation being, the porosity, $m = (V - v)/V$. The volume v was calculated from the mass of the sand used and its density. The packing of the sand was accomplished by hammering the tube with a rubber hammer while screwing in the nut with a wrench.

The density of the oil at the temperature of the bath was determined with a pycnometer.

Procedure

With a weighed quantity of sand in the tube and the gauze, spacer and nut in place, the flow tube was struck two or three times with the hammer and the nut was screwed down tight. This procedure gave the loosest stable packing of the spheres. The tube was then put in place in the constant temperature bath and enough hot oil was run through the sand to remove all the air. Rates of flow in grams per second were next observed at various pressure drops. The data were plotted as soon as they were taken. Usually runs at a half dozen different pressures were sufficient to determine the straight line through the origin. The pressure ranges varied from 3 to 16 cm. of mercury for the coarsest sand, to 18 to 96 cm. of mercury for the finest sand.

The flow tube was then removed from the bath and by hammering the tube and tightening the nut the porosity of the sand was decreased by about 1 per cent. Micrometer measurements of the change in position of the nut made possible the calculation of the new porosity. The tube was again placed in the water bath, another series of rates of flow was determined, and a second straight line was obtained. This procedure was repeated for each per cent. decrease in porosity until long continued hammering failed to allow further tightening of the nut. Data were obtained at each of five porosities for the two coarser sands and at each of four porosities for the two finer sands.

After runs had been made with the tightest packing, the tube was opened and enough sand was carefully removed to shorten the column from 22 to 10 cm. approximately. The gauze, a longer spacer and the nut were put in place and the sand was again brought to its tightest packing, the porosity of which was that of the sand for the last run made with full length sand column. A last series of runs was made with this short sand column.

Calculation of End Effect

Preliminary experimental work showed that for a given rate of flow the pressure drop through a sand column increased by increments pro-

portional to the increments of length, when the porosity of the sand was constant. All the observations showed that the rate of flow was proportional to the pressure drop. However a pressure drop as indicated by the mercury manometer was not that due to the sand alone but included that due to the gauzes and other parts of the flow tube, and to the short lengths of pipe leading to and from the flow tube. All of a given pressure drop which was not caused by the sand column, will be termed the "end effect." Since all the curves obtained were straight lines through the origin, the total end effect is proportional to the rate of flow.

These facts may be put in the form of the equation

$$P_o = (pL - e)M/t \tag{1}$$

where P_o is the observed pressure drop, M the mass of oil flowing through the sand in time t, L the length of the sand column, p the pressure drop through unit length of sand column for unit rate of flow, and e the end effect per unit rate of flow.

Thus the last two curves obtained for each sand differed in slope $P_o t/M$ only because of the difference in length of sand column. From the values of the lengths of columns and the slopes of the curves, two equations are obtained, which may be solved for e, the end effect per unit rate of flow. Preliminary experimental work indicated that e did not change with the porosity but was constant for a given sand.

Each observed pressure drop was corrected by subtracting from it, the end effect eM/t, thus obtaining the true pressure drop P through the sand alone.

Interpretation of Data

The experimental work already described shows that the rate of flow M/t varies directly as the pressure drop P through the sand alone, and inversely as the length L of the sand column. The effect of cross-sectional area A and coefficient of viscosity n were not investigated experimentally, but there are good reasons for believing that M/t varies directly as A and inversely as n. The only other factors which influence the rate of flow are the diameter d of the spheres, and the degree of packing or the porosity m. The flow formula may thus be written:

$$\frac{M}{t} = \frac{kPAd^{\alpha}m^{\beta}}{Ln} \tag{2}$$

where k, α and β are constants yet to be determined.

Calculation of β

For any one sand the quantities k, A, d and n are constant and we may write

$$R = \frac{ML}{Pt} = Cm^{\beta} \tag{3}$$

where $C = kAd^{\alpha}/n$.

Since for each sand data were obtained for four (or five) values of the porosity m, four (or five) equations (3) may be written. Solving any two for β we have

$$\beta = \frac{\log (R_1/R_2)}{\log (m_1/m_2)} \tag{4}$$

Thus in all six (or 10) values of β were calculated for one sand. The average values of β, one for each of the four sands, in the order of decreasing diameter of sand grains, were 4.27, 4.38, 4.44 and 4.80.

These values indicate that β must be a function of the diameter d. It was reasoned that β should approach a limiting value for very large grains and become very large for very small grains. An equational relation which has these characteristics in $d(\beta - a) = b$ where a and b are constants to be determined. By method of least squares two normal equations involving a and b as unknowns were formed and solved; the solution was $a = 4.14$ and $b = 0.0141$ or

$$\beta = 4.14 - 0.0141/d \tag{5}$$

Thus for sands having very large grains the exponent of the porosity becomes 4.14, while sands having infinitely small grains become impermeable since β becomes infinite.

Calculation of α

In order to calculate α, all of the values of $R = ML/Pt$ for all the sands must refer to the same value of the porosity; the value $m = 0.4$, *i. e.*, 40 per cent. was arbitrarily chosen. Since kAd^α/n and β are constant for any one sand, it is evident that the value of R for a porosity of 0.4 is

$$R_{0.4} = R_m \cdot \left(\frac{0.4}{m}\right)^\beta \tag{6}$$

where β has the value given by (5). The averages of the four (or five) values of $R_{0.4}$, one for each sand, were then calculated.

By using any two of the four average values of $R_{0.4}$ it can be readily shown that

$$\alpha = \frac{\log (R_1/R_2)_{0.4} + 0.0141(1/d_2 - 1/d_1) \log 0.4}{\log (d_1/d_2)} \tag{7}$$

The average of the six possible values of α was 1.68.

Calculation of k

It can also be readily shown that the value of k is given by the equation

$$k = \frac{R_{0.4}n}{Ad^\alpha 0.4^\beta} \tag{8}$$

By using the four average values of $R_{0.4}$ together with the proper values of α and β, four values of k were obtained, of which the average was 247. Or by changing M/t in grams per second to V/t in cubic centimeters per second, $k = 295$.

The Flow Formula

Thus the final flow formula which was determined empirically is

$$\frac{V}{t} = 295 \frac{APd^{1.68}m^{\beta}}{nL} \tag{9}$$

where V/t is the time rate of flow in cm.³/sec.,

P/L is the pressure drop in cm. of mercury per cm. length of sand column,

β is $4.14 - 0.0141/d$,

A is cross-sectional area in cm.² through which the liquid is flowing,

n is the coefficient of viscosity in dyne sec. per cm.²,

d is the diameter of a spherical grain in cm.,

and m is the porosity, *i. e.*, the fraction of the total space occupied by the sand, which is unoccupied by the grains themselves.

The following table (Table 1) indicates the accuracy of the flow

TABLE 1.—*Comparison of Observed and Calculated Rates of Flow*

Sand	Rate of Flow per Unit of Pressure Gradient			
	Porosity	Calculated	Observed	Difference, Per Cent.
No. 1	0.3870	32.70	34.50	−5.2
β = 4.28	0.3777	29.40	30.30	−2.9
d = 0.1025 cm	0.3653	25.52	26.30	−3.3
Density = 2.859 g. per cm.³	0.3533	22.12	22.87	−3.3
No. 2	0.3889	9.65	9.305	+3.6
β = 4.41	0.3779	8.51	8.52	+3.1
d = 0.0528 cm	0.3689	7.65	7.45	+2.7
Density = 2.783 g. per cm.³	0.3603	6.90	6.72	+2.7
No. 3	0.3958	7.43	7.22	+2.9
β = 4.46	0.3849	6.56	6.35	+3.3
d = 0.0443 cm	0.3715	5.60	5.527	+3.1
Density = 2.815 g. per cm.³	0.3552	4.59	4.42	+3.8
No. 4	0.3934	2.243	2.333	−3.8
β = 4.70	0.38055	1.922	1.939	−0.88
d = 0.0252 cm	0.3690	1.660	1.698	−2.2
Density = 2.802	0.3597	1.460	1.502	−2.8
Average Difference				3.1

Density of nujol at 99° C. was 0.836 grams per cm.³
Coefficient of viscosity of nujol at 99° C. was 0.050 dyne sec. per cm.²

formula for spherical-grain sands. The values of β are those given by equation (5) and not those actually calculated directly from the experi-

mental data. If the latter had been used it is obvious that smaller differences would have been found.

Conclusions

Additional work on this problem was done during the past school year with a somewhat improved apparatus and method. We were driven to the conclusion that the problem is much more difficult than had been anticipated. Really satisfactory work is not possible unless the porosities can be measured to 0.01 or 0.02 per cent. and such accuracy was not obtained.

However, the results indicate clearly that the effect on rate of flow of changes in porosity of a sand depends on the grain size. More specifically stated, a 1 per cent. change in porosity in a fine sand causes a greater percentage change of flow than does 1 per cent. change in porosity in a coarser sand. This is not in accord with Slichter's theoretical investigations. The experimental results call for the rate of flow to vary as the 1.68 power of the diameter whereas Slichter arrived at the exponent 2. In every case it was found that the rate of flow was proportional to the pressure drop through the sand. Since the pressure ranges were the same or even greater than King's, these results contradict King's results.

Another scheme for dealing with the end effects has been developed, important changes in design of the flow tube have been made, and new procedures have been devised, all of which should make possible results of the desired accuracy. It is hoped that this work can be continued in the near future.

Acknowledgments

The writer is indebted to Prof. H. C. George, Director of the School of Petroleum Engineering at the University of Oklahoma, for recommending that this investigation be carried on as a part of Project No. 33 of the American Petroleum Institute, which project he was instrumental in obtaining for the university.

The measurements were made by Messrs. John E. Owen, C. M. England and B. E. Richert, graduate students in physics, who worked successively. Nearly all the data used in this report were obtained by Mr. England. The writer is pleased to acknowledge the valuable assistance given by these men.

Variation of Pressure Gradient with Distance of Rectilinear Flow of Gas-saturated Oil and Unsaturated Oil through Unconsolidated Sands*

Part I of Final Report of A. P. I. Project No. 33

By W. F. Cloud,† Norman, Okla.

(New York Meeting, February, 1930)

The data and information compiled under Part I of this report are the results of experiments performed in the petroleum engineering laboratory under the supervision of W. F. Cloud, Associate Professor of Petroleum Engineering and William Schriever, Professor of Physics, University of Oklahoma.

Problems Being Studied

Most of the time has been spent in trying to determine the rate of flow and pressure gradient in a 4-in. flow tube 10 ft. long, which was packed with sand of various grain sizes. To date, only two kinds of sand have been packed in this tube: 60 to 80-mesh Canadian river sand, 60 to 80-mesh and 80 to 100-mesh Simpson sand. The original intention was to follow the same procedure and use the same types of crude under identical saturation pressures of both air and gas, as well as unsaturated (dead) oil, flowing the various crudes through several different sizes of both Canadian river and Simpson (Wilcox) sands, but lack of time has prevented such an intensive study of the problem.

Some additional time has been spent flowing saturated and unsaturated crudes, similar to those used in the 4-in. tube, through 1-in. tubes, one of which was 2 ft. long and one 5 ft. long. The results obtained have been checked against those obtained by using the 4-in. tube, to obtain the relation of diameter and length of tube to rate of flow in similar sands.

Laboratory Equipment

Saturation Tank.—A heavy steel cylindrical saturation tank, capacity about 42 gal. was mounted on a platform of bricks, then a galvanized tin temperature bath was built around the saturation tank. This contained

* This paper contains results obtained in an investigation on The Effect of Natural Gas on the Viscosity, Surface Tension, Adhesion and General Extractability of Crude Oil, listed as Project No. 33 of American Petroleum Institute Research. Financial assistance in this work has been received from a research fund of the American Petroleum Institute donated by John D. Rockefeller. This fund is being administered by the Institute with the cooperation of the Central Petroleum Committee of the National Research Council. Prof. H. C. George is Director of Project No. 33.

† American Petroleum Institute Research Fellow.

kerosene as a means of controlling the temperature during saturation. The kerosene was stirred continuously by a small motor mounted on the top of the tank. The tin tank was completely covered with two thicknesses of Masonite, as a means of further temperature control.

Oil was poured into the saturation tank through a funnel mounted on a ½-in. pipe outside. About 25 gal. of crude was used at each charging of the tank.

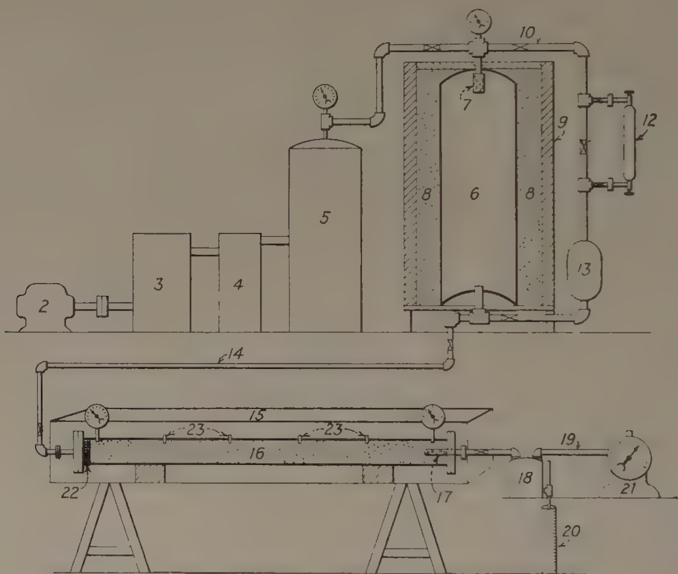

FIG. 1.—FLOW SHEET.

2. Motor.
3. Low-stage compressor.
4. High-stage compressor.
5. Receiving tank.
6. Saturation tank.
7. Nozzle on oil input line.
8. Kerosene bath-temperature control.
9. Fiber insulation.
10. Oil line from pump to saturation tank.
12. Sampling device.
13. Circulating pump.
14. Oil line to flow tube.
15. Temperature bath trough.
16. Flow tube packed with sand.
17. Perforated well oil and gas discharge.
18. Oil and gas separator.
19. Gas line to meter.
20. Oil flow measurement.
21. Wet gas meter.
22. Perforated steel plate.
23. Pressure-gage connections.

The oil was forced out of the bottom of the tank by pressure obtained from the compressor inlet at the top of the tank, thence through the circulating pump up the outside of the tank through heavily insulated ½-in. pipe to the top of the tank, where it was sprayed through a nozzle into the chamber of air or gas under pressure. Circulation was maintained until the gage pressure became constant, after which a sample of the mixture was taken.

Sampling Device.—The sampling device (Fig. 1) is attached to the ½-in. pipe leading from the pump to the nozzle at the top of the tank. By opening four needle valves and closing one disk valve on the main

flow line, a sample can be by-passed into the sampler and closed-in under the saturation pressure. The sampler is readily disconnected by means of two ⅜-in. unions. The capacity of the sampler is 375 cubic centimeters.

Measurement of Solubility.—Two methods were used to obtain the amount of air or gas absorbed by the various crudes. The sampler was strapped to the wall, and suitable ¼-in. connections made so as to convey the mixture first to a Woulff jar, which was used as a "gas trap," thence through rubber tube to a pan filled with water. The gas or air was collected in graduated cylinders over water.

The second method was by use of a gas-measuring device designed by Dr. Schriever. It consisted of a ¼-in. tube extending upward into a 2-in. tube. The 2-in. tube was kept filled with water. A 30-in. glass tube about 1¼ in. diam., drawn out at the top to a ¼-in. hole, telescoped downward over the gas eduction tube, thus being between it and the 2-in. water tube. This glass tube was calibrated in intervals of 5 cu. cm. and was raised or lowered by two pulleys and a counterbalance.

This method obtained the gas or air volume at atmospheric pressure. However, when the two methods were checked against each other, they never varied more than 10 or 15 cubic centimeters.

Flow Tube.—The inside diameter of the flow tube is 3.87 in. The length over all is 10 ft. At a distance of 6 in. back from each end, and at 1-ft. intervals thereafter, the tube was tapped for ⅜-in. pipe connections, on which the pressure gages were placed. However, during most of the flowing, only six gages were used—five of them placed 2 ft. apart, and the sixth gage, which was 6 in. back from the discharge end of the tube, only 1 ft. from gage No. 5.

The inside of the tube was swabbed with hot glue, then sprinkled with sand while the glue was still plastic, in order to prevent slippage along the inside of the steel tube.

A piece of ½-in. pipe 8 in. long was then perforated and covered with monel cloth and 115-mesh copper gauze. This tube was screwed into a bushing ½ by 1 in., the bushing then screwed into the 1-in. tap in the center of the flange at the end of the tube for a distance of about 6½ in. This method prevented the escape of sand, and eliminated the "end effect."

Maintenance of Constant Temperature.—The 10-ft. flow tube was kept submerged in a wooden trough lined with galvanized tin, the inside dimensions of which are 14 by 14 in. by 12 ft. Kerosene was used as a temperature bath, and the temperature was kept constant by electric immersion heaters, two of which are controlled by thermostats.

Measurement of Air-gas.—A Sargent monel metal wet-gas meter has been used satisfactorily for the measurement of the air or gas discharged with a given volume of saturated oil. This meter is equipped with a special dial graduated to read to 0.001 cubic foot.

Measurement of Pressures.—The pressures along the flow tube, input and discharge pressures as well as saturation pressures, were measured by specially designed and calibrated high-grade pressure gages. Extreme care was taken to use gages to suit the pressure range to which they would by subjected, and all gages used were frequently checked against a dead-weight tester.

Flow Tube Experiments

Simpson (Wilcox) Sand Screen Analysis.—The white quartz sand obtained from the outcrop of the Simpson formation at Roff, Oklahoma, has the chemical and physical analyses shown in Table 1.

Table 1.—*Analyses of White Quartz Sand*

Chemical Analysis, Per Cent.		Physical Analysis			
		Size of Opening, Inches	Mesh per Inch	Difference Between Screens, Inches	Retained on Each Screen, Per Cent.
Fe_2O_3,	0.252	0.0195	32		0.26
Al_2O_3,	0.590	0.0138	42	0.0057	1.69
CaO,	0.090	0.0110	50	0.0028	2.60
MgO,	0.028	0.0087	60	0.0023	8.18
Organic matter,	0.104	0.0082	65	0.0005	5.92
SiO_2,	98.87	0.0069	80	0.0013	8.18
		0.0058	100	0.0011	33.56
		0.0049	115	0.0009	2.34
		0.0041	150	0.0008	20.72
		0.0029	200	0.0012	11.54
		Percentage passed through 200-mesh screen			4.98
				Total	99.96

Table 2.—*Analyses of Canadian River Sand*

Size of Opening, Inches	Mesh per Inch	Difference Between Screens, Inches	Grams on Each Screen	Percentage of Total
0.0195	32		1.47	0.29
0.0138	42	0.0057	6.00	1.20
0.0110	50	0.0028	101.00	20.20
0.0087	60	0.0023	208.65	41.70
0.0082	65	0.0005	39.43	7.80
0.0069	80	0.0013	13.85	2.70
0.0058	100	0.0011	73.35	14.60
0.0049	115	0.0009	15.85	2.80
0.0041	150	0.0008	24.20	4.56
0.0029	200	0.0012	9.75	1.90
Passed through 200-mesh screen			11.20	2.20
			Total	99.95

These results are the average of five separate screenings. Five hundred grams were used in each screening. The sand was thoroughly dried before the analysis was made. Each sample was shaken 20 min. on a Ro-Tap screening machine. Standard testing sieves were used.

Canadian River Sand Screen Analysis.—This sand was obtained from the sand dunes in the Canadian river bed southwest of Norman,

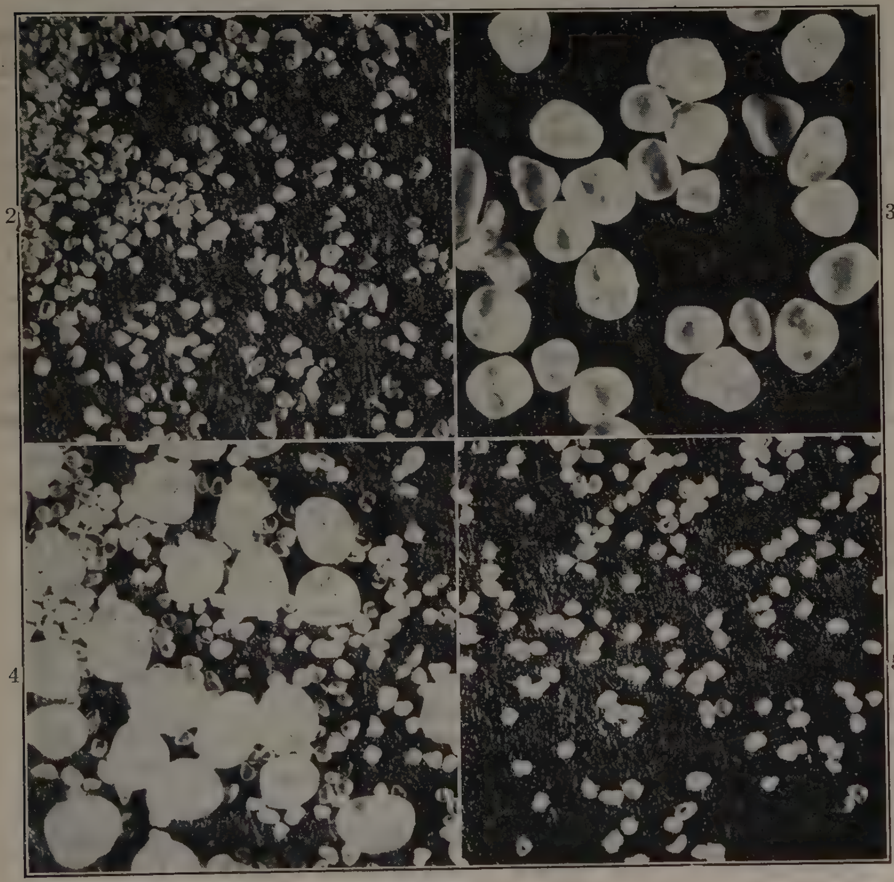

Fig. 2.—Canadian 60 to 80-mesh sand.
Fig. 3.—Ottawa 20 to 24-mesh sand.
Fig. 4.—Ottawa 20 to 24 and Simpson 60 to 80-mesh sand.
Fig. 5.—Simpson 60 to 80-mesh sand.
All × 8.

Oklahoma. The same procedure and equipment were used as in the screening of the Simpson sand (Table 2).

Figs. 2 to 5 portray the physical characteristics of 60 to 80-mesh Canadian river sand, 20 to 24 mesh Ottawa testing sand, and 60 to 80-mesh Simpson (Wilcox) sand.

Filling the Tube with Sand.—The tube is placed on end, with all openings closed with ⅜-in. plugs, to obtain the volume. This was done by filling it with a known weight of water at a known temperature. It is necessary to know the exact volume of the tube before the porosity can be calculated.

After the determination of the volume, the tube was placed on end with the perforated "well," the lower blind flange and gasket, and the gage connection nipples which are packed with lead wool and cotton, all tightly in place. The upper blind flange and gasket are removed, so the sand could be poured in at the top.

The sand of known density and grain size is thoroughly dried and weighed before being poured into the tube. Care is exercised to see that the room temperature at the time of filling the tube is at least 10° above that to be maintained in the temperature bath of the wooden trough. This should prevent the tube from expanding under the experimental pressure, as well as under the temperature of the kerosene bath.

As the sand is poured into the tube, the tube is hammered vigorously with two sledge hammers. Pouring and tamping with hammers is continued until the tube is filled, after which the upper inside perforated plate is fitted into the upper end of the tube. A strong spiral spring about 6 in. long, similar to those used on railroad car wheel trucks, is placed upon the plate. Six ½-in. bolts 8 in. long are tightened down through the flange, then the hammering is continued. As the nuts on the bolts become loose, they are tightened. In this way the hammering and tightening of the spring assist materially in getting the proper amount of sand in the tube, as well as to make a compact charge of sand of desired porosity.

After the sand is packed to the porosity required, the blind flange and gasket are put in place and tightened.

While the tube remains in a vertical position unsaturated (dead) oil is circulated in at the bottom and out at the top, in order to displace the air from between the sand grains.

The tube is then lowered into the trough containing the kerosene bath, and the proper connections (⅜-in. unions) tightened, preparatory to starting the oil flow.

Methods of Experimental Flow.—Most of the oil flows have been made at 250 lb. saturation pressure, unless "dead" oils were being run. However, the input pressure on the tube has been held at 250 lb. during almost all of the experimental flow.

The oil of known temperature, gravity, and viscosity in the saturation tank is sprayed through the air or gas space above the oil in the tank until the gage pressure becomes constant, after which a sample is taken and analyzed for solubility.

It usually requires about 3½ hr. to make a complete flow of a certain type of mixture. Four men are necessary—one to regulate the input pressure, one to regulate the various back-pressures used, one to measure the oil, and one to measure the air or gas discharged and record the data. Volumes and readings are usually taken every 5 min., but the data have been recorded at 1-min. intervals.

The different crudes used have been saturated at the same pressures and temperatures, and flowed through the same sand under identical conditions of temperature and pressure control. Usually two volume and meter readings were taken at each known pressure; but if the results varied, two other readings were taken and the four results averaged. All six gages along the tube were read at the beginning and at the end of each 5-min. run.

Gas Used.—All the natural gas used in this research work is a dry gas from the Chickasha gas field near Chickasha, Okla. It is piped into the petroleum engineering laboratory through a meter recording volume and pressure, at pressures ranging from 22 to 30 pounds.

Crude Oil Used.—The following types of crude oil were used in the experiments:

Kiefer.—A. P. I. gravity 31.5° at 60° F. Saybolt Universal viscosity 57.2 sec. at 100° F.

Tonkawa.—A. P. I. gravity 37.3° at 60° F. Saybolt Universal viscosity 39.7 sec. at 100° F.

Cromwell.—A. P. I. gravity 33.8° at 60° F. Saybolt Universal viscosity 53.6 sec. at 100° F.

Results of Flow-tube Experiments

Comparative Solubilities of Crude Oils.—Kiefer Crude.—This oil has been in storage more than 20 years. At 250 lb. saturation pressure, 375 c.c. of it will absorb 2711 c.c. of dry gas at 86° F. This is a gas oil solubility factor of 7.23.

At 86° F. it will absorb 716 c.c. of air. This amounts to an air-oil factor of 1.90.

Tonkawa Crude.—This oil is from the Wilcox sand. At 86° F. it has an A. P. I. gravity of 39.5°. The gas-oil factor of solubility is 9.50.

At the same temperature, this oil will absorb 1025 c.c. of air per sampler full (375 c.c.). This is a solubility factor of 3.00.

Cromwell Crude.—At 86° F. 375 c.c. of this oil will absorb 3125 c.c. of gas at 250 lb. pressure, a gas oil solubility factor of 8.33.

At the same pressure and temperature, 749 c.c. of air were absorbed. At 125 lb. pressure this oil absorbed 370 c.c. of air. This amount is proportional to the customary pressure of 250 lb. at the same temperature.

Unsaturated vs. Saturated Oil.— In all cases the unsaturated (dead) oil of all types flowed faster at equivalent pressures than the same oil when saturated with either air or gas.

The pressure-gradient throughout the entire length of 9 ft. along the flow tube between the pressure gages is a straight-line curve when "dead" oil is flowed; that is, the rate of flow and pressure-drop per foot for *unsaturated* oils is uniform, and it is proportional to the input or discharge pressure.

Unsaturated oil will flow faster through the same sand at the same pressure and yet maintain a lower pressure-gradient than will an oil saturated with air or gas. This is shown by the curves on (Fig. 6). This is true whether the various mixtures are back-pressured or not.

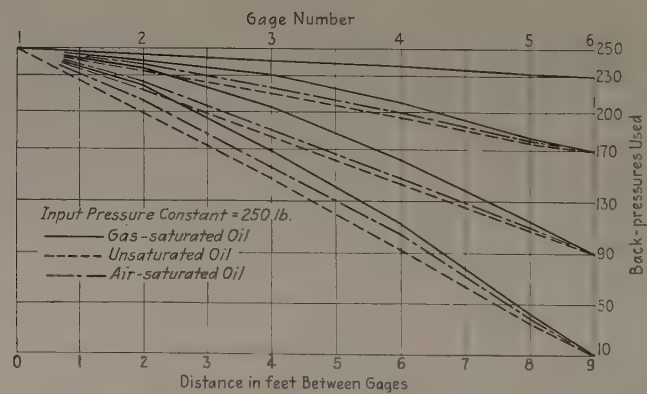

FIG. 6.—PRESSURE GRADIENTS AT VARIOUS BACK-PRESSURES.
Curves for 50,130,200 lb. are not recorded here, in order to avoid overlap of curves.

Air-saturated vs. Gas-saturated Oil.—Air-saturated oil will flow at less pressure than gas-saturated oil, and the gradient curve will be straighter. This is shown on Fig. 6.

Apparently the oils of higher gravity and low viscosity flow faster when saturated with gas, provided adequate back-pressures are used. The more viscous oils seem to flow faster when saturated with air. However, more experimental work should be done along this line before definite conclusions can be drawn.

Judging from the types of oils and the dry gas used in this work, gas is approximately 3.76 times as soluble as air at the same pressure and temperature.

Grain Size and Rate of Flow.—At 100 lb. pressure unsaturated Cromwell crude flowed 14.2 times as fast through 20 to 24-mesh Ottawa sand packed to 36.7 porosity as it did through 60 to 80-mesh Simpson sand.

Cromwell crude unsaturated flowed through 60 to 80-mesh Simpson sand at the rate of 685 c.c. per min. at 250 lb. pressure. The same crude

at the same pressure flowed at the rate of 280 c.c. per min. through 80 to 100-mesh Simpson sand.

Variation of Rate of Flow with Distance.—Unsaturated Tonkawa crude flowed through 60 to 80 Simpson sand packed in a 1-in. tube 5 ft.

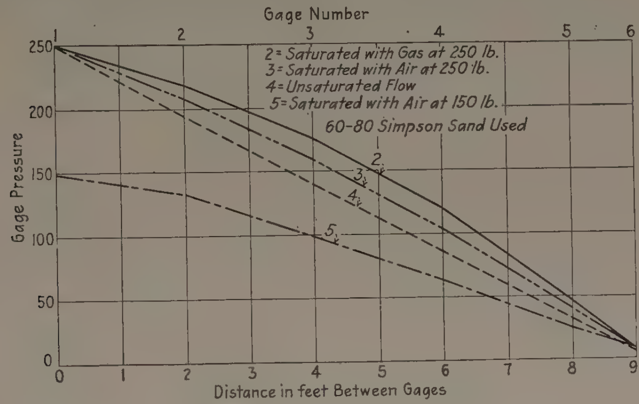

FIG. 7.—PRESSURE GRADIENTS WITH DISCHARGE VALVE WIDE OPEN.

long to 35.5 per cent. porosity at the rate of 210 c.c. per min. In a 1-in. tube 2 ft. long, using the same sand at 36.0 per cent. porosity, the same crude under the same conditions flowed 530 c.c. per minute. This means

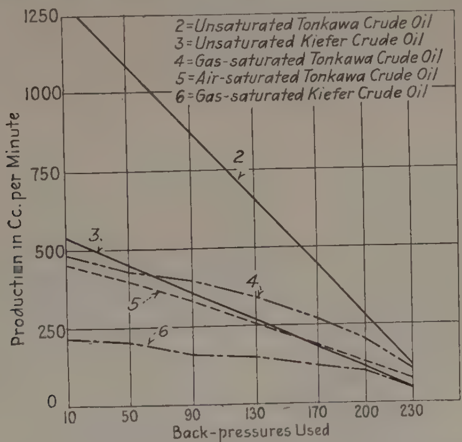

FIG. 8.—RATE OF FLOW OF VARIOUS CRUDE OILS.

that the rate of flow is inversely proportional to the length of the flow tube if the other factors are constant.

Charts and Curves.—Fig. 6 shows various pressure gradients at back-pressures of 10, 90, 170, and 230 lb. for gas-saturated, air-saturated, and unsaturated crudes. Back-pressures of 50, 130 and 200 lb. were used also, but the curves were omitted to prevent complicating the chart.

Fig. 7 shows various pressure gradients with discharge valve wide open. The oils were saturated with gas at 250 lb., with air at 150 and at 250 lb. Flow was through 60 to 80-mesh Simpson sand.

Fig. 8 shows rate of flow in cubic centimeters per minute of unsaturated Tonkawa and Kiefer crudes, gas-saturated and air-saturated Tonkawa crude, and gas-saturated Kiefer crude under back-pressures ranging from 10 to 230 lb. The input pressures were at 250 pounds.

Conclusions

While this line of research is still in its infancy and the field of application to be continued more fully in detail, the research workers feel confident in submitting the following conclusions as being typical of the work, in so far as unconsolidated sands are concerned:

1. The rate of flow of an unsaturated or saturated crude oil is inversely proportional to the length of the flow tube.
2. Unsaturated crude oils flow faster at the same input pressure than do the same oils when saturated with either air or gas at the same temperature.
3. The pressure-gradient throughout the entire length of the flow tube is a straight-line curve when unsaturated oils are used; that is, the rate of flow and pressure drop are uniform, and are proportional to the input or discharge pressure (back-pressure).
4. Air-saturated crude oil will flow faster at the same input pressure than gas-saturated oil, and the pressure-gradient curve will be straighter.
5. Viscosity is the prime factor affecting the rate of flow of an unsaturated crude oil.
6. The resistance offered by the presence of gas bubbles as gas comes out of solution in the flow tube is the prime factor affecting the rate of flow of a saturated oil.
7. Gas-saturated crude oils of low viscosity respond better to back-pressure control than do air-saturated or unsaturated oils.
8. A slight change in temperature will more readily affect the rate of flow of an unsaturated oil than it will a saturated oil.
9. Gas or air bubbles in a saturated mixture cause least resistance to flow when high back-pressures are used, and are released slowly to pressures below the input pressure. Applying high back-pressure after gas-saturated or air-saturated crude has been subjected to open flow will not obtain the same rate of flow as would be obtained by gradually opening the discharge valve to high back-pressure, permitting the gas to come out of solution slowly, thus controlling the size of the bubbles between the sand grains. Bubbles when once formed are difficult to reduce in size sufficiently to reestablish the initial rate of flow as obtained at higher back-pressures.

DISCUSSION

H. C. George,* Norman, Okla.—I am particularly interested in some deductions to be made from the results secured by Professor Cloud and Dr. Schriever in connection with A. P. I. Project No. 33. Since the decrease in flow from an oil sand to a well is due to an escape of gas from the oil in excess of the gas-oil ratio and the obstruction resulting from the presence of this gas in the form of bubbles in the sand near the well opening, caused by this excess gas coming out of solution with the decrease in pressure as the oil approaches the well, why not in new fields try the experiment of operating all wells with no well producing at less than the initial rock pressure? This statement doubtless sounds rather peculiar.

H. H. Hill,† New York, N. Y.—How will you get any flow of oil?

H. C. George.—Let us take a hypothetical case. Suppose you have a small closed structure with an initial rock pressure of, say, 300 lb. per sq. in. Assume that all wells are completed before any are produced. Build up a differential pressure above the initial rock pressure by compressing gas or air, introduce this compressed gas into key wells and at the producing wells maintain a back-pressure on the sand equivalent to the initial rock pressure. The building up of this differential at the key wells should cause the oil to move towards the producing wells with none of the gas coming out of solution within the sand, and we should have the same condition of flow as when dead oil or oil free from gas is flowing through a sand.

H. H. Hill.—You will have to maintain a considerably higher pressure than the rock pressure, in order to hold the rock pressure at the well, because I believe the results to date have indicated that there is an appreciable drop in pressure just a few inches from the well.

H. C. George.—Of course the oil itself, the minute the well is tapped, will rise in the well to a head equivalent to the rock pressure existing.

F. M. Brewster,‡ Bradford, Pa.—Does it not all tend to show that what you are trying to approach is a hydrostatic pressure?

H. C. George.—That is what we have.

F. M. Brewster.—It is going to cost too much money. Take the Bradford field as a good example. There we want to get as big a differential as we can across the wells to get our flow. We are taking out twice as much oil as was originally taken out naturally. We have a 2000-lb. differential across a space of 175 ft., and we are getting more oil. To my way of thinking, it shows that what Chalmers brought out, and what Herold brought out, indicates that more oil is obtained, and that is what we are interested in, by approaching as near as possible to a constant push, and of course, the ultimate in that would be the hydrostatic push.

H. C. George.—I am talking about new fields with the initial rock pressure, where the wells have never produced and no gas has ever been permitted to come out of solution. I am satisfied, in my own mind, that there are some oil fields where this method will work.

H. H. Hill.—I think it is going to be a practical proposition of getting the gas into the sand. The gas will go into solution very slowly through the input wells,

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† Petroleum Engineer, Standard Oil Development Co.

‡ General Manager, Belmont Quadrangle Drilling Corpn.

and in order to get much movement you may have to use pressures several times the rock pressure.

H. C. George.—It would be like kicking off an air-gas lift well; the starting is going to be most difficult.

F. M. Brewster.—Your main object is to keep that gas in solution and not let it expand?

H. C. George.—Yes.

F. M. Brewster.—Why not put fluid in the intake well? Take a new field at 300 lb. You do not want to put any more gas in, because that is troublesome now, and you do not want it to expand. Instead of introducing gas, why not put in water or some other fluid, with no gas in it? And it is easier to repressure by liquid.

H. C. George.—I thought of that, but you must admit that at Bradford the introduction of water has trapped a great deal of oil. My idea of utilizing the gas is that if a condition of this sort had existed, the gas would have been in a reservoir after the oil was removed, and be there as a resource.

H. H. Hill.—This finding at the University of Oklahoma is very important and is different from the results of past experiments. The original experiments that were made by Beecher and Parkhurst and by the U. S. Bureau of Mines, have indicated decided advantages of dissolving gas in oil, reducing the viscosity and surface tension, and therefore enabling the oil to move more readily through the sand. Here we have a case just the opposite, a gas-free oil, in other words, an oil that has been standing for 20 years or so, actually flowing through the sand more readily than when this same oil is saturated with gas.

J. Chalmers,* Washington, D. C.—In maintaining the pressure differential and the output pressure such that the gas will stay in solution, there is great danger of forming a channel through the sand. We know that, depending upon the size of the interstices of the sand, there is a capillary retention of the oil which tends to hold the oil in suspension through the thickness of the sand. Under certain sand conditions in the field, the coarser portions of the sand may be thin enough so that the force of capillary retention is sufficient to hold whatever oil there is in the sand evenly distributed from top to bottom. But there are other sand conditions in which the size of the interstices and the thickness of the sand body are great enough to allow a gravitational separation of the oil and gas in the sand. The minute that takes place there will be slippage of the introduced gas along the top of the sand, and, that is just the point, where, allowing the gas to expand from solution has its greatest benefit. If there is that tendency for a gravitational settling of the oil, allowing the dissolved gas to expand from solution will tend to counteract it, maintaining a more perfect seal across the thickness of the section of sand and giving the pressure media something to work against, in order to drive the oil out of the sand.

I. I. Gardescu,† Pittsburgh, Pa.—I wish to call attention to a contribution by Dr. Augustus Föppl on the flow of ground water into a well.[1] Dr. E. B. Wilson, of Harvard, who has been actively engaged in the study of problems of drainage and flow of water in sand reservoirs, considers Föppl's equation much nearer actual field data than either Poiseuille's or Schlichter's equations.

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† Petroleum Engineer, Research Department, Gulf Production Co.

[1] A. Föppl: *Vorlesungen über Tech. Mechanik,* **6**, 450–452.

The author points out the possibility of applying the data obtained from flow experiments on dead oil to the flow of oil and gas through sand. The resistance of gas bubbles in capillary tubes is not representative of the true resistance of gas bubbles confined to sand interstices. The resistance of the bubbles is a function of their size, number, and distribution. The experiments referred to do not seem to be representative of the flowing conditions in the reservoir sand. In these experiments the pressure gradients were relatively large and the flow of sufficient velocity to carry the bubbles along as soon as they formed. Under these conditions it is possible that the dynamic resistance of the gas bubbles is constant, as shown by experimental data. However, where the pressure gradient is small and the rate of flow is reduced, the resistance of gas bubbles is not constant and experimental data show that the range of variation is very great. The static resistance of the gas bubbles is apparently much greater than the dynamic resistance. The experiments I refer to were performed at small pressures. Whether the same holds true at high pressures, I do not know, but the subject should be investigated more thoroughly before the analogy with dead oil can be made.

C. S. Corbett,* New York, N. Y. (written discussion).—The suggestion of Professor George that it would be advantageous to take production from an absolutely new field at back-pressure equal to or greater than the reservoir pressure is of great interest and seems to possess unusual possibilities for completeness of extraction.

It involves raising the pressure within the reservoir formation to a point where production can be secured without permitting any of the dissolved gas to come out of solution. From the oral discussion one gets the impression that the general reaction to the idea is that although it is interesting it is also rather impractical. Unquestionably it presents problems the solution of which the results cannot be definitely foreseen at this time but it also seems to have merits that warrant serious consideration.

To raise the reservoir pressure requires the forcing of gas or liquid into the sand before extraction begins. It has been suggested that if gas were used there would be further solution of gas in the oil, which would tend to defeat the purpose of the pressure-raising operation. In addition, Mr. Chalmers argues that gravity separation in the sand around the input wells would result in gas moving from input to outlet wells without performing the desired work. So far as the introduced gas goes into solution in the oil, there would not be an accumulation of this gas under gravity control and, to that extent, the two objectionable features could not both be operative.

It seems probable that the introduced gas would readily go into solution in the oil if the two were intimately mixed and the oil subjected to any important stirring action. If so, the gas should certainly not be injected through oil wells, as Mr. Chalmers assumed would be done, but should be introduced into crest wells which penetrate the sand in the free-gas area. In this way solution of additional gas in the oil would be kept at a minimum, since it could proceed no faster than diffusion would permit aided only by the slight stirring effect which would accompany downward movement of the oil toward producing wells. The nature of the reservoir space would tend strongly to inhibit any stirring effect under the slow motion that would prevail.

The system would be somewhat analogous to that of lifting water from a closed tank by pumping air into the top of the tank and letting the water emerge by way of a pipe leading out from the bottom of the tank. The analogy is strengthened if we assume that we are dealing with carbonated water and pumping in CO_2 gas as the driving agent, the carbonated water escaping through a check valve set at a pressure sufficient to prevent escape of CO_2 gas from solution in the tank or pipes.

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* Geologist, Gulf Oil Co.

The success of the method using gas drive would probably depend mainly, if not entirely, upon the rate of solution of gas in oil under the increased pressure, which in turn depends upon the rate of diffusion of gas dissolved in oil. I have not found any published information regarding the rate of diffusion of gas in oil. Some research to secure appropriate data would be desirable. It would seem that Professor George's experimentation could readily be carried further to test out his suggestion and it is to be hoped that he will find an opportunity to do this.

Should rapid solution of gas prevent extraction of oil at a pressure equal to or higher than reservoir pressure by means of the gas drive, there remains the possibility of using water drive. It would be undesirable to introduce water in a new field in any structural position other than through edge-water wells. In other words, line flooding would have to be used to prevent the shutting off by introduced water of large quantities of oil, which would inevitably result from the use of the five-spot or seven-spot methods of flooding.

Without entering into a discussion of each item, it may be worth while to list the advantages which each method—gas drive and water drive—may have over the other in taking the production under back-pressure equal to or exceeding formation pressure.

Advantages of Water Drive

1. Avoidance of the gas-solution effect already discussed as possibly offering a serious drawback to the use of gas drive.

2. Lower pump pressures required, since the hydrostatic pressure in the input wells would supply a considerable portion of the total pressure needed for recovering the oil.

3. Opportunity to use and market the gas from the field currently with the operation of the field.

Advantages of Gas Drive

1. Less friction of movement of gas through sand than of water.

2. Saving of much of the pressure of the gas coming out of solution in the crude by double trapping, the gas from the higher pressure trap being taken to high-stage compressors for return to the sand.

3. Smoother surface between oil and gas than between oil and water because of the greater specific gravity difference between the former; therefore less by-passing of oil by gas drive than by water drive.

4. Oil by-passed by gas would remain free draining and would have a long time to flow down dip to join again the main body of oil.

5. Smaller investment in drilled wells required to initiate production, because (1) the edge of the field would not first have to be found and (2) a much smaller number of input wells would be necessary to introduce gas in the free-gas area than to maintain a line drive with water.

6. Opportunity to rework the field with water drive after it has been completely worked over by gas drive.

Behavior of Gas Bubbles in Capillary Spaces*

By Ionel I. Gardescu,† Pittsburgh, Pa.

(New York Meeting, February, 1930)

Natural gas influences the movement of oil through reservoir rock by affecting the physical properties of the oil and the pressure within the reservoir. The presence of gas bubbles changes the laws of flow and the distribution of forces.

The problem of flow of oil and gas through a porous rock is complex, and most authors, in order to analyze their problems, have found it necessary to make or accept certain generalized assumptions. Some of these assumptions, particularly the ones dealing with capillary phenomena and molecular forces, have not received sufficient attention and by lack of understanding have often been misinterpreted.

Herold[1] has called attention to the resistance offered by gas bubbles in capillary spaces and has drawn some interesting conclusions with regard to the action of natural gas in a reservoir rock. He has duplicated an experiment of the French physicist Jamin, has interpreted his findings in terms of molar mechanics, and, from experimental observations, has made a number of assumptions which he later applies in discussing problems of natural flow and recovery of oil. The Jamin action is an assumption because it lacks a physical proof and has never been determined quantitatively.

Tickell[2] attempts to develop a formula expressing the work performed by a distorted bubble. H. A. Wilson, in the recent publication of the American Petroleum Institute on the function of natural gas, discusses the phenomenon in terms of classical physics. Both contributions are incomplete and offer no experimental data.

This paper includes a study of the static condition of equilibrium of gas and liquid bubbles confined to capillary spaces. In order to avoid any possible confusion, it is proposed to restrict the term "Jamin action"

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* Portion of a thesis presented by the author in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Petroleum Engineering, University of California.

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[1] S. Herold: Analytical Principles of the Production of Oil, Gas, and Water from Wells. Stanford Univ. Press, 1928.

[2] F. G. Tickell: Capillary Phenomena as Related to Oil Production. *Trans.* A. I. M. E., Petroleum Development and Technology (1928–29) 343.

to a boundary effect caused by the hysteresis of the angle of contact of the liquid gas interface with the solid surface. The Jamin action as defined occurs both in uniformly and irregularly shaped capillary spaces whenever the liquid does not "wet" the solid walls. The distortion of gas bubbles when forced through small openings is herein discussed as a separate phenomenon. The distortion of gas bubbles in motion will not be included in the present paper.

The Jamin Action

The Jamin action is the resistance caused by the boundary condition of detached gas and liquid bubbles confined to capillary spaces.

In a uniform capillary tube the whole system of alternating liquid and gas bubbles is referred to by Poynting and Thomson as the Jamin tubes, which they describe as follows:[3]

> . . . they are simply capillary tubes containing a large number of detached drops of liquid; these can stand an enormous difference in pressure between the end of the tube without any appreciable movement of the drops along the tube. Thus, suppose that *AB*, *CD*, *EF* (Fig. 1) represent three consecutive drops along the tube, then in consequence of the different curvatures of *AB* at *A* and *B* the pressure in the air at *A* will be greater than at *B*, while the pressure at *C* will be greater than at *D*, and so on; thus each drop transmits a smaller pressure than it receives, if we have a large number of drops in the tube the difference in pressure at the ends arising in this way may amount to several atmospheres.

FIG. 1.—CONSECUTIVE DROPS IN CAPILLARY TUBE.

The resistance of the bubble is independent of its length (Stanley Herold) since it is caused by a boundary condition at the two extremities of the bubble. The same phenomenon is observed if a column of liquid, confined to a small tube, is subjected to a slight displacement. The column of liquid will behave like an elongated bubble.

If mercury is forced up a narrow capillary tube and then the pressure is gradually diminished, the mercury at first, instead of falling in the tube, adjusts itself to the diminished pressure by altering the curvature of its meniscus; it is only when the fall of pressure becomes too large for such an adjustment to be possible that the mercury falls in the tube; the consequence is that the fall of the mercury, instead of being continuous, takes place by a series of jumps (Poynting and Thomson).

In 1866, M. Nageli,[4] in studying the motion of a column of water in a capillary tube, proved that there is a resistance to flow offered by the surface meniscus of the water column. He assumes that the resistance

[3] J. H. Poynting and J. J. Thomson: A Text Book on Physics. Properties of Matter, 142. London, 1914. C. Griffin & Co., Ltd.

[4] M. Nageli: Über die Theorie der Capillarität. *Bull.* Acad. of Science of Munich (1866) **1**, 597.

is due to an increase in viscosity of the interface and explains the Jamin action in terms of this theory.

In 1898, Charles Wolf[5] stated that "the meniscus acts as a wall or diaphragm, preventing the liquid immediately behind it from moving more rapidly along the axis of the tube than along the walls of the tube. The knowledge of the retarding influence of the meniscus would have important applications in the seepage of water through porous media."

In 1916, Marcel R. Daly[6] discussed the Jamin action in connection with the "sealing up" condition of a pool. He expressed the resistance offered by the bubbles in terms of surface tension and the difference of the cosines of the angles of contact.

Hysteresis of Angle of Contact

To better understand the Jamin action, it is necessary to discuss the variation of the angle of wetting. Edser[7] gives the following description: "when a liquid does not spread over a solid, the surface of the liquid joins the solid at an angle which, within certain limits, is definite. The angle between the surface of the liquid and the solid-liquid interface (Fig. 2) is called the contact angle for the solid and liquid." If S_1 is the gas-solid surface tension, S_{12} the solid-liquid surface tension and S_2 the gas-liquid surface tension, the following relationship must exist when the system is in equilibrium:

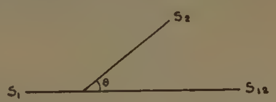

Fig. 2.—Contact angle for solid and liquid.

$$S_1 = S_{12} + S_2 \cos\theta$$

or

$$\cos\theta = \frac{S_1 - S_{12}}{S_2} \qquad [1]$$

In order to "wet" a surface, the contact angle must be reduced to zero. In other words, the difference between the surface tension of the solid and the surface tension of the solid-liquid interface must be equal to or greater than the surface tension of the liquid.

Sulman[8] found that for most solids in contact with water, the observed value of the contact angle depends on the way in which the first condition is arrived at. When a liquid reaches its final state of equilibrium by spreading over the dry surface of a solid, the contact angle is greater than when the liquid reaches its final state of equilibrium by receding

[5] C. Wolf: The Unsteady Motion of Viscous Liquids in Capillary Tubes. *Trans.* Wisconsin Acad. of Science, **12**.

[6] M. R. Daly: The Diastrophic Theory. *Trans.* A. I. M. E. (1916) **56**, 733.

[7] E. Edser: The Concentration of Minerals by Flotation. British Assn. for Adv. of Science, Fourth Report on Colloid Chemistry, 289.

[8] H. L. Sulman: A Contribution to the Study of Flotation. *Trans.* Inst. of Min. and Met. (1919–20) **29**. Hysteresis of contact angles, 88.

from a previously wetted surface. It has been suggested by Sulman that $(\theta' - \theta)$, the difference between the maximum and minimum values of the contact angle, should be called the hysteresis of the contact angle. This difference, although variable, runs in the neighborhood of 50°.

Scarlett, Morgan and Hilderbrand[9] give the following account with regard to the hysteresis of the contact angle:

A plane surface of the solid is inclined to such an angle that the liquid-gas interface remained horizontal, as tested by oblique reflection, right up to the solid surface (Fig. 3). It was found, however, that a horizontal interface could be maintained over long periods of time with widely different angles of inclination of the plate. An interface which climbs up the plate may be made horizontal either by increasing the inclination of the plate toward the horizontal, or by lowering it with inclination unchanged. It was expected at first that a true equilibrium angle of contact would be approached if sufficient time were allowed. It was found, however, that the inclination of the plate could be varied over wide angles without giving rise to any movement of the line of contact over periods up to 24 hours.

FIG. 3.—HYSTERESIS OF CONTACT ANGLE.

The Jamin Tube

Consider now the Jamin tube and assume that the liquid does not wet the surface of the glass. Let θ and θ' be the two angles of contact (Fig. 4). From A to B the surface of the glass is wetted by a liquid, while from B to C the surface of the glass is dry. Considering a slight displacement of the bubble from A to A' and B to B', it will be noticed that at B the liquid comes in contact with a dry surface, while at A the liquid comes in contact with a wet surface. The contact angle θ' is greater than θ.

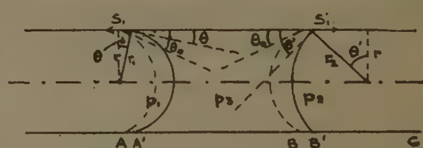

FIG. 4.—HYSTERESIS OF CONTACT ANGLE IN JAMIN TUBE.

The law of minimum free energy tends to bring the meniscus of the liquid to a spherical surface. We can, therefore, readily calculate, as a first approximation, the two radii:

$$r_1 = \frac{r}{\cos\theta} \text{ and } r_2 = \frac{r}{\cos\theta'} \qquad [2]$$

Writing the equation of Laplace for the pressures exerted on the interfaces,

$$p_1 = p_3 + \frac{2S_2}{r_1} \text{ and } p_2 = p_3 + \frac{2S_2}{r_2}$$

$$\therefore p = p_1 - p_2 = 2S_2\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

[9] A. J. Scarlett, W. L. Morgan and J. H. Hilderbrand: Emulsification by Solid Powders. *Jnl. Phys. Chem.* (1927) **31,** 1567.

by substituting the values from equation 2 for r_1 and r_2

$$p = \frac{2S_2}{r}(\cos\theta - \cos\theta') \qquad [3]$$

Edser[10] expresses the hysteresis of the angle of contact in terms of surface tension by assuming that the surface of the solid from which the liquid has just receded has a surface tension higher than the surface tension of the original dry surface. In other words, S_1 is greater than S_1'. S_{12} and S_2 are respectively equal[11] to S_{12}' and S_2'. We can therefore write:

$$\cos\theta - \cos\theta' = \frac{S_1 - S_{12}}{S_2} - \frac{S_1' - S_{12}'}{S_2'} = \frac{S_1 - S_1'}{S_2}$$

Substituting in equation 3

$$p = \frac{2}{r}(S_1 - S_1') \qquad [4]$$

The resistance p opposed by the bubble is proportionate to the variation of the solid-surface tension and inversely proportionate to the radius of the capillary tube. The equation is independent of S_2, the liquid-surface tension, and has only a theoretical significance, because no satisfactory method has yet been developed by which the surface tension of a solid can be measured. Equation 3 can readily be computed when the values of θ and θ' are known. Assuming that we had a way of calculating the variation of the solid surface tension, we could easily compute therefrom the value of p or "f" which is maximum for a maximum difference between θ and θ'.

It should be noted that the equations are independent of the length of the bubble. The resistance is caused by a boundary condition along the line of contact of the three phases.

Apparatus Used in Experiments

Fig. 6 represents a diagrammatic sketch of the apparatus shown in Fig. 5.

The apparatus consists of a fine capillary tube *xyz* provided with two enlargements *j* and *m*. The radius of the capillary tube is 0.011 cm. Enlargement *j* serves to receive the gas bubble subjected to distortion. Enlargement *m* connects the capillary tube with pressure reservoir 1. The difference in pressure on the two ends of the gas bubble is recorded by the difference in level of the liquid in reservoirs 1 and 2. Burettes 4 and 5 are used for obtaining the gas bubble which is forced

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[10] E. Edser: *Op. cit.*, 292.

[11] J. W. McBain, Stanford University, says that it is possible for S_2 to be also affected by an increased adsorption or by the packing of impurities along the contact line of the interface.

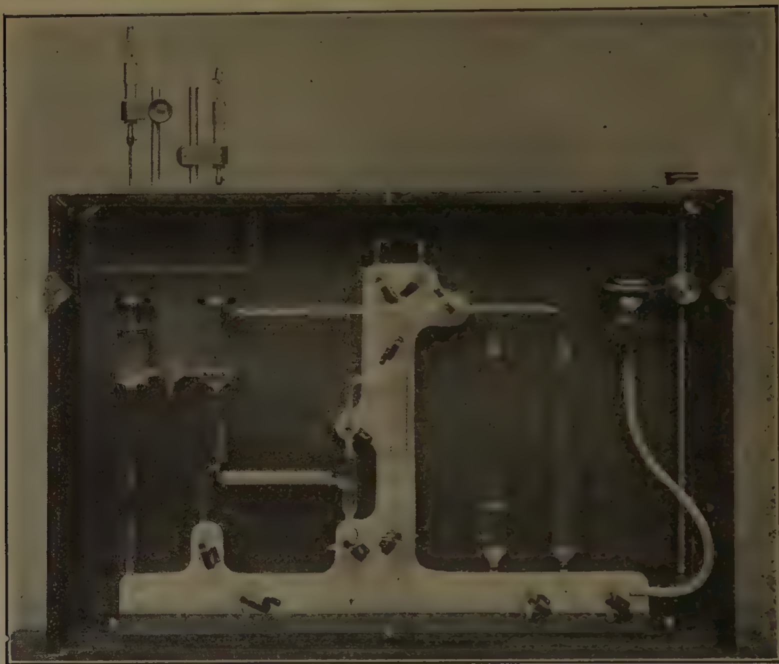

FIG. 5.—APPARATUS FOR MEASURING RESISTANCE OF GAS BUBBLES FORCED THROUGH CAPILLARY OPENINGS.

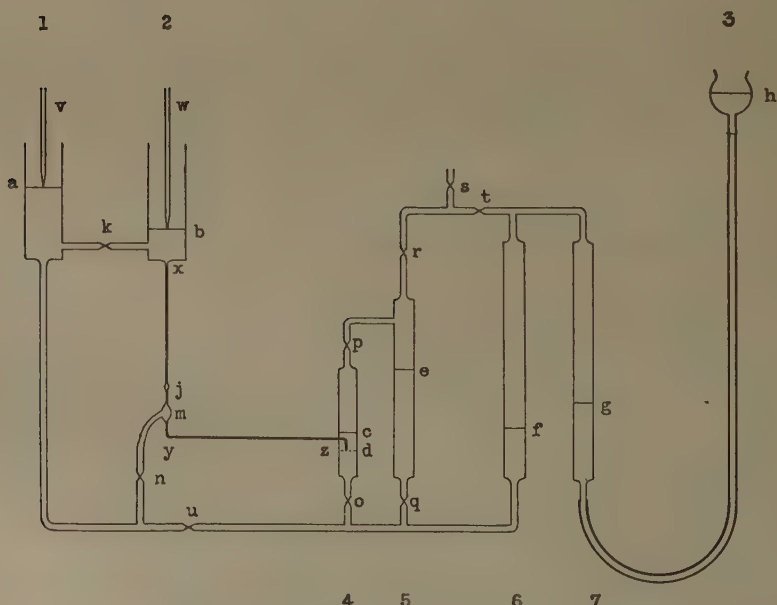

FIG. 6.—DIAGRAMMATIC SKETCH OF APPARATUS.

into the capillary *yz*. Burette 7 transmits the pressure from the leveling reservoir 3 through the intermediate burette 6. It was necessary to have the two burettes 6 and 7, which do not communicate except through the upper part, because burette 7 is contaminated by the rubber tubing connecting it with reservoir 3.

Before it is used, the whole apparatus is thoroughly cleaned, including the stopcocks. The liquid to be used is then introduced through reservoir 1. Stopcocks *u*, *o*, *p* and *k* are closed. The liquid fills enlargement *m*. Part flows into burette 4 through capillary *yz* and part fills up enlargement *j* and rises to reservoir 2. As soon as the liquid has reached reservoir 2, stopcock *k* is opened and both reservoirs are filled. Stopcock *u* is opened and all burettes are filled to the top. When all the air has been eliminated, stopcock *s* is closed and tube *s* is connected to a tank containing the gas used in the experiment. The gas is introduced through *s*, displacing part of the liquid. Burette 7 is connected to reservoir 3, both being filled with water and care being taken not to let any of the enclosed gas become contaminated. To catch a bubble, the stopcocks *t*, *r*, *o* and *u* are kept closed and all the others are opened. By raising reservoir 3, the pressure in 6 forces the water level *f* down, *e* up and *c* down. When *c* reaches the level *d*, gas begins to enter the capillary tube at *z*. By proper adjustment of reservoir 3 a suitable bubble length is obtained in the capillary tube. When stopcock *o* is opened, the water level *d* will rise and catch the bubble without changing the pressure of the system because stopcock *p* is kept open and the volumes of both liquid and gas remain unchanged. This is very important because the slightest variation in pressure will force the bubble out of the capillary tube. The tube *yz* serves to measure the bubble, its radius (0.011 cm.) being known. Stopcock *n* is closed and the bubble is forced into *m* and then into *j*. Stopcocks *n* and *k* are both left open and *u*, *o* and *p* are closed. The two micrometers are adjusted to read the level of the liquid in 1 and 2; *k* is closed, *u* is opened and the pressure in reservoir 1 is increased by lifting reservoir 3. Before any pressure is applied the bubble in *j* has a shape approaching a sphere. As the pressure is increased the bubble advances toward the capillary tube. The maximum pressure is reached when the upper end of the bubble has just penetrated into the smallest capillary space. The pressure is recorded by the difference between the readings of the two micrometers. One determination consumes 4 to 5 hr. Getting the bubble into the capillary tube *yz* is the most difficult part of the operation.

Experiment 1

A bubble of methyl alcohol was introduced in capillary tube *yz*. All stopcocks were closed excepting *o* and *u*. The micrometers were

adjusted and the position of one of the menisei of the bubble was read against the horizontal scale attached to the capillary *yz*. The micrometer readings are given to 0.0001 in. The position of the bubble can be read to 0.1 mm. and the first two readings given in Table 1 are taken at 5-min. intervals. The readings of the micrometers and the position of the bubble during the experiment are given in Table 1.

TABLE 1

Position of Bubble	Micrometer 1	Micrometer 2	Difference between Readings	Differential Pressure[a]	Displacement of Bubble, Cm.
460–460	506.1	647.8	141.8	0.0	none
460–470	507.5	549.0	141.4	0.4	0.10
470–500	508.0	549.0	141.0	0.8	0.30
555–595	512.5	652.5	140.0	1.8	0.40
595–650	513.5	653.2	139.7	2.1	0.55
650–715	517.0	656.5	139.5	2.3	0.65
715–780	520.0	659.5	139.5	2.3	0.65

[a] Thousandths of an inch of alcohol.

Methyl alcohol wets the glass. The glass tube was thoroughly cleaned and did not come in contact with air or any other contaminating medium. The angle of contact of alcohol and glass would be zero at both extremities of the bubble. According to theory there would be no resistance due to the Jamin action, since there is no variation in the angle of wetting.

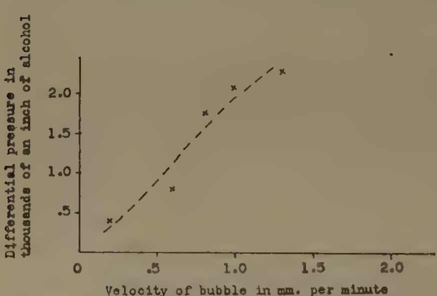

FIG. 7.—RELATIONSHIP BETWEEN PRESSURES APPLIED AT EXTREMITIES OF ALCOHOL BUBBLE CONFINED IN CAPILLARY TUBE AND VELOCITY OF DISPLACEMENT OF BUBBLE.

Fig. 7 shows the relationship between the pressures applied at the two extremities of the alcohol bubble confined to the capillary tube and the velocity of displacement of the bubble. The author believes that much smaller pressures than 0.0004 in. of alcohol could maintain the gas bubble in motion in a clean capillary tube of uniform size. The same bubble when forced through the capillary opening *j* required a differential pressure of 1.36 in. of alcohol.

The experiments seem to justify the statement that there is no Jamin effect when perfect wetting exists between the liquid and the solid. Similar results have been obtained by other investigators. J. Plateau,[12]

[12] J. Plateau: Statique des Liquides Soumis aux Seules Forces Moléculaires. **2.** 80–82 (1873).

in repeating the Jamin experiments, proves that the cause of the resistance recorded in the case of water bubbles and glass tubes is only due to contamination. After cleaning the glass tube with concentrated potassium hydroxide, which was allowed to stay in the tube for 24 hr., the resistance opposed by the water bubbles was very small. After 5 min., a greater resistance was recorded, and after the tube was exposed to the atmosphere for 15 min. before introducing the bubbles, the value of the resistance was similar to the one given by Jamin. At the Mellon Institute, W. O. Smith[13] has caused artificial contamination of the tubes and shown that the resistance increases with the degree of contamination.

The magnitude of the angle of wetting is independent of the orientation of the solid surface. If the orientation of the solid surface changes, the surface of the liquid in the vicinity of the solid changes with it but the angle of contact will remain the same. If the angle is zero it will remain zero.

Experiments indicated that oil wets an uncontaminated glass or quartz surface and produces an angle of contact equal to zero; therefore in an oil sand there will be no phenomenon of hysteresis of the angle of contact and no Jamin effect. The phenomenon cannot be checked by direct measurements because it cannot be dissociated from the resistance caused by distortion of the gas bubbles when forced through the irregular openings of the sand pores. Furthermore, the magnitude of the resistance offered by gas bubbles is so much greater than any possible resistance caused by the Jamin effect that the presence of the latter would be unnoticeable.

Distortion of Gas Bubbles When Forced through Capillary Openings

A small gas bubble, at rest, in a liquid medium, will take a spherical shape because the surface of the surrounding liquid tends to contract to the smallest area admissible. On the surface surrounding the gas bubble, or the gas-liquid interface, there is a greater concentration of gas molecules than within the rest of the bubble. These molecules are attracted or adsorbed because of the free energy of the liquid surface. The pressures exerted on one side and the other of the interface are not equal. The pressure is less underneath a concave surface, and the following relationship exists:

$$p_1 = p_2 + \frac{2S}{r}$$

or the excess pressure on the inside of the bubble is equal to

$$p = \frac{2S}{r}$$

[13] W. O. Smith: Private communication.

in which S is the surface tension of the liquid and r the radius of the bubble.

When two soap bubbles of unequal size are connected by a glass tube (Fig. 8) it will be noticed that the smaller bubble blows out into the larger bubble. To prevent this and to maintain the two bubbles in equilibrium, it is necessary to apply a certain amount of pressure against the large bubble. In the case of a spherical soap bubble, there are two tensions to be considered, one on the inner side of the film and the other on the outer side; hence the excess pressure inside the bubble, due to the tension and curvature of the film, is $\frac{4S}{r}$. To avoid any unnecessary complications, let us assume that the fluid outside the bubble is a liquid and inside the bubble is a gas. There will be only one surface tension to be considered. If p_1 is the inside pressure (Fig. 8),

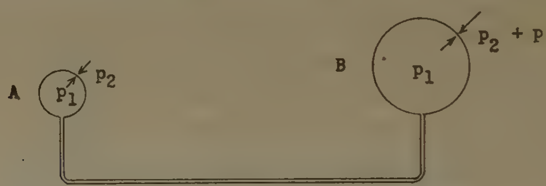

FIG. 8.—SOAP BUBBLES IN EQUILIBRIUM.

p_2 the outside pressure exerted upon the bubble A, and $p_2 + p$ the pressure exerted upon bubble B, in order to maintain the bubbles in equilibrium, the following equations must be satisfied:

$$p_1 = p_2 + \frac{2S}{r_1} \text{ and } p_1 = p_2 + p + \frac{2S}{r_2}$$

Therefore

$$p = \frac{2S}{r_1} - \frac{2S}{r_2} = 2S\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

When a gas bubble is forced through a reduced opening, the same phenomenon is observed. The two spheres are replaced by the menisci A and B (Fig. 9) and the connecting tube by the capillary opening pm, $p'm'$. Thus, the problem being similar to the previous case, the pressure to be applied against the large bubble will be

$$p = 2S\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

The equation can be derived by expressing the variation in pressure on each side of the two menisci, as previously done for the soap bubbles.

In a conical section, as the bubble A moves a small distance from m to n (Fig. 9) bubble B will advance a greater distance from p to q because the volume between the spherical surfaces mm' and nn' has to be equal to the volume between the spherical surfaces pp' and qq'. As the bubble

advances, r_1 will decrease much more rapidly than r_2, therefore, $\frac{1}{r_1}$ will increase more rapidly than $\frac{1}{r_2}$ and p will be at a maximum when r_1 is at a minimum, or equal to r, the radius of the capillary opening.

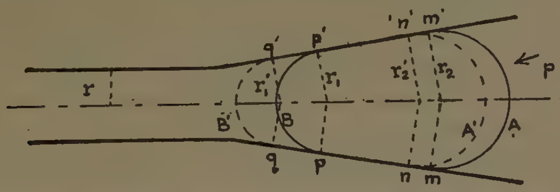

FIG. 9.—CHANGE IN FORM OF GAS BUBBLE FORCED THROUGH REDUCED OPENING.

Before any pressure is applied against the surface A, the bubble is spherical. The effect of buoyancy on the distortion of the bubble is relatively small but becomes appreciable when the bubble is of about the same size as the capillary opening. As the pressure is increased against the surface A, the bubble takes a pear shape (Fig. 10b), the neck of which is gradually lengthened as the pressure applied against the bubble is increased. The bubble will stay in this distorted position for an indefinite length of time or can be brought back to its original shape by removing the pressure. When the curvature of the upper meniscus is equal to r (Fig. 10c) the whole bubble will shoot through the capillary tube independently of the size of the bubble.

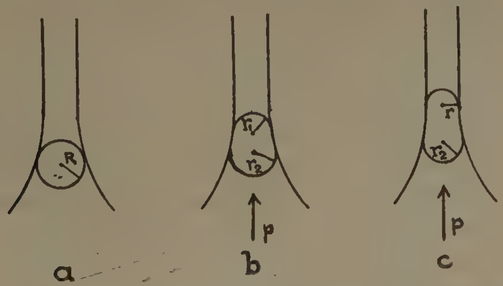

FIG. 10.—CHANGE IN FORM OF GAS BUBBLE FORCED THROUGH REDUCED OPENING.

Considering the equation

$$p = 2S\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

p is at first zero when the bubble is spherical and $r_1 = r_2$. A small decrease of r_1 corresponds to a small decrease of r_2, but r_1 decreases more rapidly than r_2, therefore p must be increased as the difference between $\frac{1}{r_1}$ and $\frac{1}{r_2}$ becomes greater in order to maintain the bubble in a position of equi-

librium. Maximum is reached when r_1 is equal to r, which is the minimum value that r_1 can assume. Thereafter r_1 will remain constant, while r_2 will continue to decrease, and consequently p will also decrease until it reaches again the value zero when r_2 is equal to r_1 and both equal to r.

Other methods for computing the resistance offered by gas bubbles have been suggested. When the bubble changes its shape, the work performed by the bubble can be calculated by integrating the pressure times the distance traveled by each liquid particle within the limits of distortion. The work can also be derived from the variation of the free energy of the interface, which is equal to the increase in free surface of the bubble times the surface tension of the liquid. The latter method was used by Tickell. The computation by volume is very complicated and the variation of the free energy of the interface is not proportionate to the variation of p.

By forcing a bubble into a cylindrical capillary tube, the total surface of the bubble will be gradually increased until the whole bubble is confined to the capillary tube. The surface of the two menisci of the bubble decreases and becomes minimum when the total surface is at a maximum. The variation of p, as already described, is entirely different; therefore the maximum value of p cannot be calculated from the increase in the surface of the distorted bubble because the two quantities vary independently of each other.

Experiment 2

The same apparatus described for the experiments on the Jamin action was used for the experiments on distortion of gas bubbles.

A gas bubble was measured in capillary tube yz (Fig. 5) and driven into enlargement j against the vertical capillary opening. Stopcocks k and n were kept open and repeated readings were taken on the two micrometers to determine the position of equilibrium. Stopcock k was closed and the level a in reservoir 1 was raised by raising the leveling reservoir 3. Although the level in 2 changed only slightly, chiefly because

Table 2.—*Size of Gas Bubble*

Bubble No.	Length, Cm.	Volume, Cu. Cm.	R, Cm.	r_2, Cm.
1	0.05	0.000019	0.016	0.0115
2	0.11	0.000042	0.021	0.0130
3	0.27	0.000103	0.029	0.0190
4	0.55	0.000209	0.037	0.0290
5	0.70	0.000266	0.040	0.0323
6	0.96	0.000365	0.044	0.0372
7	1.70	0.000646	0.054	0.0490
8	2.65	0.001007	0.062	0.0578

of variations in temperature, readings were always made on both micrometers. Approximate determinations were made at first for alcohol, kerosene and water. Water proved to be unsatisfactory because the contamination of the liquid surface made the readings with the micrometer points unreliable. In the more accurate determinations methyl alcohol was used because it is easy to handle and has a surface tension of approximately the same value as oil.

Table 2 gives the size of the gas bubbles used. The radius of the spherical bubble R is computed from the volume measured in the horizontal capillary yz. The length of the bubble in the horizontal capillary is given in column 1. The computation of r_2 is shown further in the paper.

Table 3 gives the observed and computed values of p calculated from the equation $p = 2S\left(\frac{1}{r_1} - \frac{1}{r_2}\right)\cdot r_1$. The radius of the capillary is equal to 0.011 cm. The surface tension of methyl alcohol was taken as 23. In the first column the differential pressure h of the two reservoirs is given in inches of alcohol. The same pressure is shown in column 2 in C.G.S. units, calculated from the equation

$$p = 2.54hdg$$

d and g being the density of methyl alcohol (0.792) and the acceleration of gravity (980).

TABLE 3.—*Observed and Computed Values of p*

Bubble No.	Differential Pressure, Inches	Recorded[a] Pressure C.G.S.	r_2	Computed Value of p
1	0.038	75	0.0115	180
2	0.371	731	0.0130	640
3	0.955	1882	0.019	1540
4	1.310	2582	0.029	2590
5	1.362	2684	0.032	2760
6	1.494	2945	0.037	2950
7	1.726[b]	3402	0.049	3220
8	1.736	3422	0.058	3390

[a] To the figures in this column should be added the differential pressure due to buoyancy which is about 23 for bubble 1 and increases to about 54 for bubble 8. The greatest error is due to the difficulty encountered in computing r_2 to a required approximation of one-thousandth centimeter.

[b] The value of the observed pressure is greater than the corresponding maximum value of p. The bubble was moving more rapidly through the capillary than in the other experiments.

The values given in Table 3 are shown in Fig. 11. The observed value of bubble 7 was expected to be greater because of experimental

inaccuracy. The observed value of bubble 3 is considered correct. The discrepancy arises from the fact that the value of p has been cal-

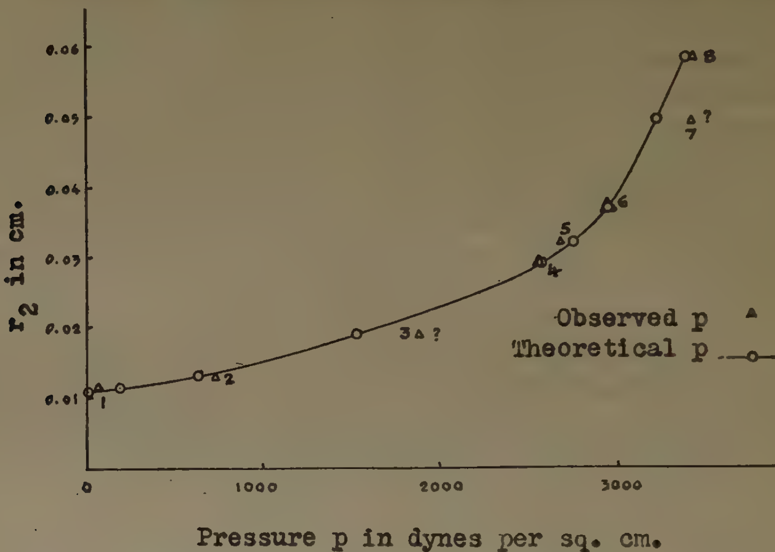

FIG. 11.—RELATION OF r_2 TO OBSERVED AND THEORETICAL PRESSURE.

culated from the equation $p = 2S\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$ on the assumption that p is maximum for the maximum value of r_2 corresponding to a minimum

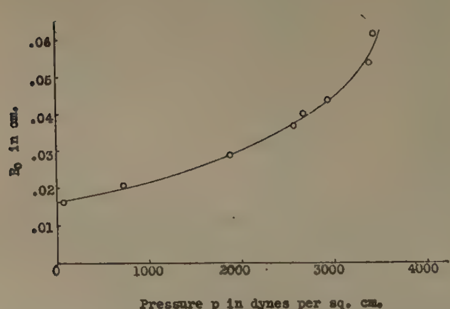

FIG. 12.—RELATION OF OBSERVED PRESSURE TO R_0.

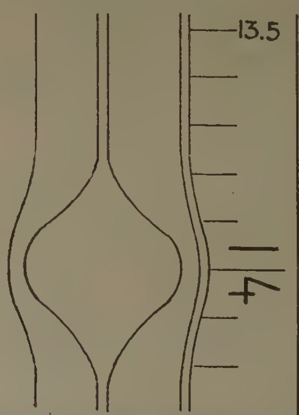

FIG. 13.—CAPILLARY TUBE MAGNIFIED 10 TIMES.

value of r_1 equal to 0.011 cm. It will be shown further that this assumption does not hold true for bubbles of all sizes on account of the irregularly shaped capillary opening.

Fig. 13 shows the capillary tube magnified 10 times. The maximum pressure necessary to force the bubble into the capillary tube is reached after the upper meniscus is above 13.8 on the scale. The exact position could not be determined but lies between 13.7 and 13.6. The value of r_1 between these two points ranges from 0.012 to 0.011 cm. Experimental data show that the point at which the maximum pressure is reached is independent of the size of the bubble; that is, does not depend upon r_2. The magnitude of the maximum pressure of course, is, dependent upon r_2 as the experiments described in the previous section indicate.

The equation $p = 2S\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$ shows that p has its maximum value, independent of r_2 only when $\frac{1}{r_1}$ increases more rapidly than $\frac{1}{r_2}$, for r_1 minimum. In the case of a conical section it can be proved easily that r_1 does decrease more rapidly than r_2. If the conical section terminates in a cylindrical tube of radius r, the maximum value of p is reached when r_1 is equal to r.

The portion of the enlargement j used is nearly a conical section, with a cylindrical tube and to a first approximation the position of the maximum pressure is reached when r_1 is equal to r, which was observed. For a bubble of volume 0.493 cu. mm. it was computed that upon forcing the bubble into the capillary, $\frac{1}{r_1}$ had the values 2.1, 7.1 and 8.3 corresponding to 2.1, 2.1 and 2.3 for $\frac{1}{r_2}$. This shows that $\frac{1}{r_2}$ varies little in comparison with $\frac{1}{r_1}$ in the capillary used. This is especially true of large bubbles and very small bubbles. However, when r_2 is small it is possible to have r_2 decrease more rapidly than r_1 and in that case the maximum of $\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$ will not take place when $\frac{1}{r_1}$ is maximum but when the whole parenthesis becomes maximum. The size of bubble No. 3, as already mentioned, probably corresponds to one of these critical conditions.

In Fig. 12 the observed values of p maximum have been plotted against R, the radius of the original spherical bubble. R is easily calculated from the volume of the cylindrical bubble measured in the capillary tube yz. R is only slightly larger than r_2 for large bubbles, especially when r, the capillary opening, is small. For small bubbles R is much larger than r_2 and cannot be used in the computations shown in Fig. 11. For this reason the values of p computed against R, Fig. 12, will differ from the theoretical curve shown in Fig. 11. The curve shows a general relationship between the size of the bubble and the corresponding values of p.

Fig. 14 illustrates the method by which r_2 was computed. The diagram shows a number of six bubbles of various sizes confined to the capillary tube and forced into the capillary enlargement j until the

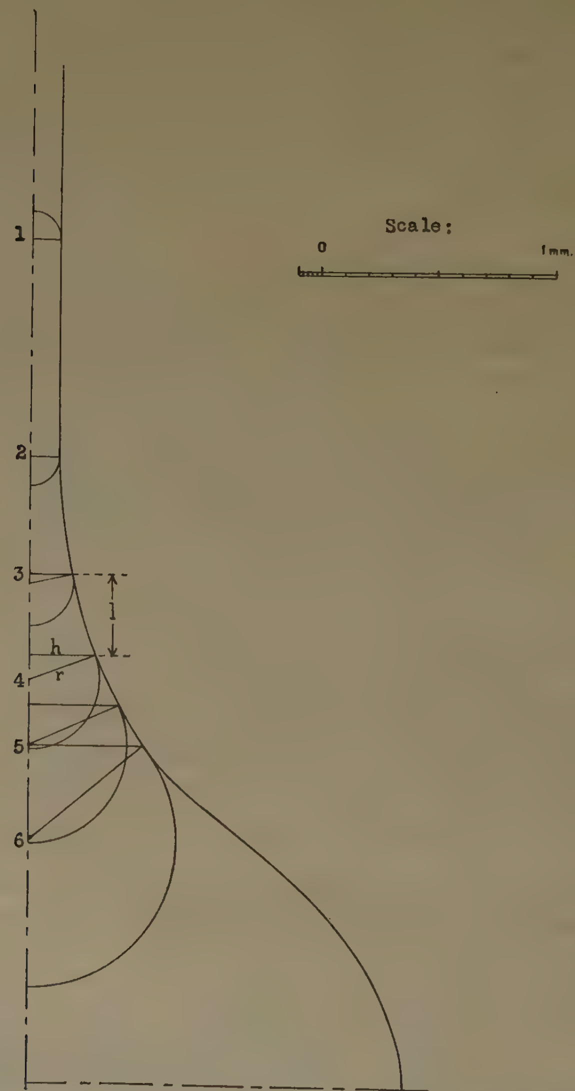

Fig. 14.—Longitudinal section through capillary and enlargement.

upper meniscus has reached the position marked 1. The volume of each distorted bubble was calculated and the value of R, the radius of the corresponding sphere was computed from that. The computations are given in Table 4.

TABLE 4.—*Computation of R*

Number of Bubble	r_2[a]	l[a]	h[a]	r[a]	Volume of Sphere	Volume of Cone	Total Volume	R[a]
1	0.110			0.11	2,787		2,787	0.11
2	0.122	0.95		0.122	3,859	40,162	46,808	0.223
3	0.180	0.50	0.156	0.175	14,643	35,008	92,600	0.281
4	0.295	0.35	0.195	0.280	80,060	57,920	215,937	0.372
5	0.422	0.22	0.242	0.390	251,991	78,261	466,129	0.481
6	0.650	0.18	0.250	0.500	1,039,050	110,664	1,363,852	0.688

[a] Given in millimeters. Volumes are 10^{-6} mm.^{3}.

Fig. 15 shows the values of R plotted against r_2.

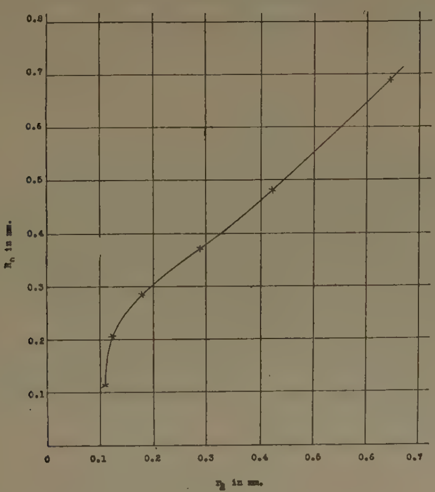

FIG. 15.—RELATION OF R_0 TO r_2.

The shape of the capillary shown in Fig. 14 was obtained by measuring the distorted image of the capillary enlargement and by adjusting it according to volumetric measurements of the inner chamber.

CONCLUSIONS

The Jamin action is the resistance offered by detached gas and liquid bubbles confined to capillary tubes by a boundary condition which develops whenever the liquid does not wet the solid walls of the capillary. The resistance opposed by the bubble is proportionate to the variation of the solid-surface-tension at the two extremities of each individual liquid bubble and is inversely proportionate to the radius of the capillary tube. For oil and sand the Jamin effect is zero or very small. The

resistance p offered by a gas bubble when forced into a capillary opening is given by the equation:

$$p = 2S\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

in which S is the surface tension, r_1 the interporous opening through which the bubble is forced, and r_2 the maximum curvature of the distorted bubble, when the curvature at the other extremity of the bubble is r_1.

To be forced through a capillary opening of 0.011 cm. diameter, a gas bubble, present in a liquid medium of surface tension equal to 23, will require a pressure of from zero to 4000 dynes, depending on its size.

The magnitude of resistance offered by gas bubbles forced through small openings so far exceeds any possible resistance caused by the Jamin effect that the latter phenomenon need scarcely be considered in dealing with the movement of oil and gas through their natural reservoir rocks.

DISCUSSION

S. C. Herold,* Los Angeles, Calif.—Mr. Gardescu's introduction to his paper contains a regrettable feature. His restriction of the term Jamin action to "a boundary effect caused by the hysteresis of the angle of contact of the liquid-gas interface with the solid surface," thus excluding from the term the effects to which he has given particular study and of which the results constitute the main thesis of his paper—"the resistance offered by gas bubbles forced through small openings"—is unwarranted, unjust and misleading. Both features constitute Jamin action. Jamin himself studied both, and commented at length upon the greater intensity of one of them. The fact that Poynting and Thomson fail to mention the more intense feature in their necessarily concise textbook has no significance. It is proper that we refer instead to Jamin's memoir.[14]

In view of the fact that there are the two distinguishable features, Mr. Gardescu's desire to differentiate them is comprehensible. To be strictly ethical in his terminology he might have made the distinction between, say, Jamin action major and Jamin action minor. In this there would be clarity and at the same time full justice to others who have heretofore filed in the archives of physical science a literature which includes the subject of Jamin action. Mr. Gardescu can not ask these authors to agree to his restriction—the principal one is not here to defend his priority right, having long since passed from our ranks.

If Mr. Gardescu will generously comply with our urge to modify his statement, he will agree that his last paragraph shall read as follows:

"The magnitude of resistance by gas bubbles forced through small openings (Jamin action major) so far exceeds any possible resistance caused by the boundary effect due to the hysteresis of the angle of contact of the liquid-gas interface with the solid surface (Jamin action minor), that the latter phenomenon need scarcely be considered in dealing with the movement of oil and gas through their natural reservoir rocks."

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* Petroleum Geologist.

[14] J. Jamin: Memoire sur l'équilibre et le mouvement des liquides dans les corps poreux. *Compt. rend.* (1860) **50**, 172, 311, 385.

With a like restatement of the case in the middle of page 359, we have, I believe, the truth at hand. Jamin action minor is of slight intensity. Owners of wells producing in capillary control can be thankful that it is so. If Jamin action in natural reservoirs were confined to the major effect, these wells would not be able to produce 1 per cent. of the amount of oil and gas which they are now able to do. Laboratory experiments show this to be the case. We observe that slight effects can be of economic importance. They can not be neglected because they are slight.

As for the main portion of Mr. Gardescu's paper, we need only say that it is excellent. It is an elucidating summation of our knowledge of film phenomena, to which he contributes not a little. His apparatus is unique and it appears to be capable of precise manipulation.

I would ask Mr. Gardescu if he can conveniently perform a time experiment with his apparatus. Place a bubble in the enlargement *j*, Fig. 6, apply a pressure sufficiently intense to distort it, say to cause it to take the position shown in *b*, Fig. 10, close all stopcocks, and allow the apparatus to stand some weeks to see if there is any indication of the migration of gas molecules through the overlying liquid. It has been claimed that gas molecules will enter the meniscus under stress, pass along the liquid and escape from an opposite meniscus such as a *b*, Fig. 6, provided sufficient time is allowed. This migration, if it takes place, would obviously establish an equilibrium between the two meniscuses, permitting the bubble to retract in *j* and take on a shape more nearly spherical.

H. A. Wilson,* Houston, Texas (written discussion).—Mr. Gardescu's conclusion that the Jamin effect is unimportant in the case of oil flowing through sand depends upon his definition of what is meant by the Jamin effect. I should have thought that the resistance to the motion of the gas bubbles through the pores in the sand, which he finds is large, was a large Jamin effect. I do not think it is customary to regard the Jamin effect as being only the effect in tubes of uniform diameter. Jamin experimented with uniform and nonuniform tubes. In the case of uniform tubes, which of course are never found in sand, the effect must be much smaller than in nonuniform tubes. When the liquid wets the surface in a uniform tube we should expect an effect about proportional to the velocity, as Mr. Gardescu finds. His results show that a single bubble in a uniform tube 0.011 cm. radius gives a pressure of 0.002 in. alcohol when moving 2 mm. per minute. If the velocity was 2 mm. per second the pressure would be 0.12 in., which represents a large Jamin effect; 0.12 in. per bubble would give very large pressures in sand.

I. I. Gardescu.—To those who have used the term "Jamin action" in referring to both phenomena, restricting the term might be confusing and, as Mr. Herold says, might seem unjust. May I call attention to the fact that not very long ago Mr. Wilson in his chapter on the Jamin effect[16] discusses only the second phenomenon, while Professor Tickell[17] discusses only the first phenomenon of the same Jamin action, thus creating a very confusing conception of what the Jamin action really means.

I agree with Mr. Herold on the interpretation of the last paragraph of the paper. To make the statement more general, it may read as follows:

The magnitude of resistance of gas bubbles subjected to mechanical distortion when forced through small openings so far exceeds any possible resistance caused by the distortion of the meniscus due to the hysteresis of the angle of contact of the oil-gas interface with the sand grain surface that the latter phenomenon need scarcely

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* Department of Physics, Rice Institute.

[16] H. A. Wilson: Chapter in Function of Natural Gas in Production of Oil, by H. C. Miller. New York, 1929. Amer. Petr. Inst.

[17] F. G. Tickell: *Op. cit.*

be considered in dealing with the movement of oil and gas through their natural reservoir rocks.

Mr. Herold's suggestion that the bubble be allowed to rest against the capillary opening for several weeks is very well taken and I will communicate the results obtained.

I did not restrict the term Jamin action to the effect in tubes of uniform diameter. I defined Jamin action as the resistance caused by a boundary effect due to the hysteresis of the angle of contact, whether it takes place in a uniform or nonuniform capillary tube. However, the phenomenon has been studied in a uniform tube because it simplifies the problem by eliminating the resistance caused by the mechanical distortion of the bubble.

The computation given by Mr. Wilson does not take into account the resistance due to viscous flow of the liquid column. My contention is that I could not obtain a static resistance such as recorded in the second phenomenon.

H. C. George,* Norman, Okla.—With reference to the movement of the bubbles through the capillary tube it seems to me that there probably will be some interesting things brought out when the film of oil used on the interior of these tubes is of varied viscosity and varied gravity. It is of particular interest to me to see what the rate of movement is under varying conditions.

I. I. Gardescu.—In a condition of motion, I believe that the viscosity would be an important factor. In the present study of static equilibrium, the viscosity need not be taken into account.

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* Director, School of Petroleum Engineering, University of Oklahoma.

Chapter IX. Cementing Wells

Cementing Problem on the Gulf Coast

By H. D. Wilde, Jr.,* Houston, Texas

(New York Meeting, February, 1930)

At the Sugarland and Raccoon Bend fields in the Gulf Coast area, all wells are drilled with rotary tools and the casing is always set in cement that is placed by the circulation method. After the cement is set, the rotary mud that fills the hole is not withdrawn or bailed out; consequently, it is not customary to give the cementing job a direct test either by putting pressure on the hole to see whether the cement will hold or by observing whether an effective water shut-off is secured.

About three years ago, this company started the practice of coring the cement left in the bottom of the casing and examining the core thus secured. If the core was hard and strong, the cementing job was judged a success but if the core was incoherent, soft, and crumbly, the job was considered a failure. Of course, there were intermediate types of cores and it was not always a simple matter from this examination to decide whether the job was a success or failure. After about two years, a summary of the core examinations that had been made indicated that of cementing jobs made at depths of 1000 ft. or less, 60 per cent. were failures; of those between 1000 and 2000 ft., 80 per cent. were failures, and of those between 3000 to 6200 ft., 100 per cent. were failures. This startling table emphasized the need of the study of the conditions under which the wells were cemented and of adopting means to reduce the percentage of failures.

In addition to these core tests, two wells gave direct evidence that the cementing jobs were not always successful. In one, a four-year-old well at Goose Creek, the casing was perforated, and when fluid was circulated some of the old cement was brought to the surface. Most of it was powdery and the few chunks that were brought up were soft and crumbly. The other was a well at Raccoon Bend which during a blow-out brought a number of chalky, soft and crumbly pieces of cement to the surface.

Suggested Explanations of Cementing Failures

Efforts were made at once to explain the causes of these cementing failures. As all of the cements used were of a high grade and gave

* Director of Production Research, Development Department, Humble Oil Refining Co.

satisfactory results when specimens were set above ground, it appeared that the trouble in the well might be due to the heat and pressure at the bottom of the hole, which might prevent the cement from setting properly. However, work at the laboratory of one of the cement manufacturers showed that as the temperature increased the cement set more rapidly, and that with temperatures up to 165° F., the strength of the cement after two days increased markedly as the temperature increased. Pressures of 2100 lb. had little effect upon the setting time or final strength of the cement. A few supplementary tests were made in the company laboratories in which cement was placed in a bomb or strong container and then mud pumped in to give a pressure of 2200 lb. per sq. in. and the temperature held at 125° F. The specimens set under heat and pressure were much stronger than similar specimens set under atmospheric pressure at 72°. As in the majority of wells, the temperatures do not greatly exceed 130° or 135°, it appeared that the trouble was not due to the pressure and temperature existing at the bottom of the well.

The soft, chalky and crumbly specimens of cement that had been in place for some time in the wells at Goose Creek and Raccoon Bend were analyzed and found to contain a large percentage of carbon dioxide, indicating that the cement compounds had been converted to carbonates, which were much softer and had much less strength than the original cement material. This fact led to the theory of carbonation. It was believed that carbon dioxide contained in the gas from the formation reacted with the cement as it was setting and that the resulting carbonates were responsible for the failure of the cement. To test this theory, several samples of the cement were placed in a bomb, the bomb was filled with carbon dioxide gas from a cylinder, and then drilling mud which had previously been saturated with carbon dioxide was pumped in to give a pressure of about 2200 lb. The resulting specimens were firm and strong and seemed not to have suffered at all from the carbon dioxide. On analysis, these specimens showed the presence of only small amounts of carbonates. As the concentration of the carbon dioxide in these experiments was many times as great as could exist at the bottom of the well and yet did not injure the cement in any way, it became apparent that the case of the poor cores that were removed a few days after the cement had set were not due to conversion to carbonates. This did not prove, however, that the soft cores that had been in place in the wells at Goose Creek and Raccoon Bend had not been altered in their composition by the reaction of carbon dioxide, for these had been in contact with carbon dioxide for a long period.

As most of the laboratory specimens had been prepared with city tap water instead of the field waters actually used in the field operations, it was thought that the failures might have been due to the presence of salts in the field waters, which interfered with the setting of the cement.

Laboratory analysis of the waters in question did not reveal the presence of any injurious salts, and laboratory specimens prepared with these waters gave sound results. The failures, therefore, could not be attributed to the composition of the water used in making the cement slurries.

Thus, one by one, the explanations that occurred to those working with the problem were shown to have little effect upon the success or failure of the cementing. The problem was then attacked with renewed vigor and studied from three angles: (1) a laboratory study of the effect of the use of excess water and mud contamination on the setting of cement, (2) a petrographic study of the cement cores taken from the wells and of specimens prepared in the laboratory under controlled conditions, and (3) the observation of cementing operations in the field with the view of detecting the causes of trouble in the light of the findings of the two studies and of correcting them. These three phases were closely interrelated and all contributed to the same final conclusion.

Laboratory Study

The laboratory study was started by making chemical analyses of cement pats prepared in the laboratory, muds and cement cores from the field. Muds from Raccoon Bend and from West Texas both showed about 20 per cent. loss on ignition, 55 per cent. silica and 15 per cent. lime. They differed only in their content of aluminum oxide and ferric oxide, the Raccoon Bend mud containing about 4 per cent. and the West Texas about 12 per cent. A laboratory pat containing only cement and water showed 25 per cent. loss on ignition, 16 per cent. silica, and 54 per cent. lime. A sample of cement mix that was actually used in the field for cementing a well was set above ground in contact with mud and on analysis was found to be almost identical in composition with the pat prepared in the laboratory. The principal difference between the composition of the muds and the cements was in the silica and lime contents, the cement containing much less silica and much more lime. Three cement cores taken from wells were analyzed; their silica and lime contents were found to be intermediate between those of the pure cements and the mud. A good core had a low silica and high lime content, approaching that of pure cement, whereas a poor core had a high silica and low lime content similar to mud. A moderately poor core had silica and lime contents intermediate between these two. These findings pointed to the fact that the well cores were contaminated with mud and that in general the poorer the core, the more mud it contained.

As it was known that there was a tendency in the field to make the cement mix as thin as possible to insure its easy pumping into the well, some laboratory work was undertaken to study the effect of excess water as well as mud contamination on the strength of the cement. A series of samples was prepared with varying amounts of water. A definite

amount of the mix was placed in a 4-oz. oil-sample bottle; the bottle was tightly stoppered and set aside undisturbed for 72 hr. In the thinner mixes, the cement settled to the bottom of the bottle, leaving a layer of clear water on top. The amount of clear water was measured, then the bottle was broken and the strength of the cement pat was tested.

Mixes containing less than 65 parts by weight of water per 100 parts of dry cement did not form a clear water layer. It is not believed that all of the water reacted chemically to hydrate the cement, as only about 30 to 35 parts of water are usually required, but that the excess of water remained in the pore spaces formed by the cement crystals. As the amount of water in the mix increased beyond 65 parts, the amount of water in the water layer also increased, but not proportionally, which indicated that the amount enclosed in the cement pores per part of dry cement increased as the excess of water increased. The solid cement that settled to the bottom formed a strong substantial specimen. The actual tensile strength was not determined, but inspection showed that the specimens were strong. There was a tendency for the mixtures that had contained the greater amount of water to form weaker specimens. When a large excess of water had been used, a graduation in the cement that settled to the bottom was noticeable and the lower portions appeared stronger and the upper portions weaker.

A number of mixes were prepared with excess water and instead of being allowed to remain undisturbed were agitated while the cement was setting. Some were agitated by turning the bottle end for end every 10 minutes during the setting period and the remainder were agitated by bubbling a small stream of air through the mixture. This agitation prevented the cement from settling and the entire amount of excess water was enclosed in the cement specimen. The specimens were allowed to stand undisturbed for three or four days. When examined, they were all very damp, soft and porous, with a number of tiny water pockets. After these specimens had dried for several days, they were still soft and crumbly. These experiments showed that excess water is not seriously objectionable provided nothing is done to the mixture to prevent the settling of the cement particles and the formation of a clear water layer on top. If this settling is interfered with, by agitation with formation gas or by other means, a poor cement core will result.

The effect of lack of uniformity of the water content of the cement mix was illustrated by filling a glass tube of 1 in. dia. with alternate layers of thick and thin mixtures. Several days later, when the tube was examined, it contained alternate portions of strong and weak cement. Apparently, there was insufficient time for the entire cement portion to settle. The more concentrated portions set more rapidly than the less concentrated and after they had set the settling was confined to the zones

between the solidified portions, which caused the alternately strong and weak layers.

Contamination with Drilling Mud

Some laboratory work was undertaken to study the effect of contamination with the drilling mud upon the strength of the cement. In most of these experiments, the mud was from Raccoon Bend and represented a Gulf Coast drilling mud, but in some cases mud from West Texas was used. The results were not materially affected by the type of mud used. Series of mixes were made using varying amounts of water and to these mixes various amounts of mud were added. The mixtures were allowed to set for 72 hr. in stoppered 4-oz. sample bottles.

When the mixture contained less than about 65 parts of water per 100 parts of dry cement, no clear water gathered on top. The addition of the mud weakened the specimens; the greater the amount of mud, the weaker the specimens. With mixes that had been prepared with more than 65 parts of water per 100 of cement, a clear water layer gathered on top but the amount of water was less than it would have been if no mud had been added, and an increase in the amount of mud decreased the amount of water that gathered. The effect of the mud on the specimen was very much the same as though the mixture had been agitated to prevent settling.

Small amounts of mud were effective in preventing the settling of the cement. With a mixture containing 120 parts of water per 100 of cement the presence of as little as 1 per cent. mud decreased the amount of water gathered on top from 18 to 8 c.c. With a mixture containing 100 parts of water per 100 parts of cement, the water layer was reduced from 16 to 10 c.c. As the amount of mud was increased, the size of the water layer decreased and by adding enough mud, the water layer could be reduced to almost nothing. The addition of 10 per cent. mud was usually enough to reduce the water layer to a small fraction of the original value.

Specimens containing excess water and little mud looked very much like specimens with the corresponding amount of water that had been agitated to prevent the cement from settling . As the mud content increased, the specimens became correspondingly weaker. Pats containing equal quantities of water and cement to which 10 per cent. of mud had been added were soft and crumbly when dry and were easily crushed between the fingers, and resembled some of the poorest cores from the wells. Many of the laboratory specimens that contained less excess water and to which less mud had been added resembled some of the cores of the wells that were rated as poor cores.

In mixes containing a large excess of water to which mud had been added, there was a gradation in quality from the bottom to the top of the specimen, the bottom being stronger and the top weaker. There were

some cases where the bottom was quite sound, whereas the top was soft and worthless.

Petrographic Study

In the petrographic study of this problem, 55 specimens of cement were examined. Of these, 9 were prepared in the laboratory as experimental controls and 46 were cores taken from wells at depths ranging from 100 to 3500 ft. and varying in appearance from excellent looking cores to crumbly incoherent failures. There seemed to be no correlation between the failures and the depth from which they were taken, as some of the best cores came from the deepest wells, whereas some of the cement used for surface casing produced very poor cores. Each sample was examined by inspection as to apparent success or failure of the cementing job, hardness, brittleness, type of fracture and porosity. Thin sections were prepared and examined under the microscope. They were examined for degree of hydration, amount and kind of foreign matter, evidence of formation of carbonates, and type of fabric. It might be well to define what is meant by "fabric." This term is used to signify the relation between the crystalline and amorphous material, the size of the crystals and the amount of interlocking of the crystals.

There was a good correlation between the appearance of the cores on inspection and the appearance under the microscope. A laboratory specimen of 33 parts of water per 100 of cement which, of course, looked excellent on inspection, had an excellent fabric, moderate amount of hydration, no foreign material and although it showed a slight conversion to carbonate, this was limited to one border of the specimen. Sets containing increased amounts of water showed poorer fabrics and a greater degree of hydration. Sets to which mud had been added indicated poor fabrics and the presence of the mud could be detected easily. Where mud was added to thick mixtures, the mud was present in islands but where it was added to thin mixtures it was evenly distributed throughout the mixture. The mud could be identified by the presence of grains of pyrite, quartz and feldspar.

In all soft, crumbly well cores, the fabric and degree of hydration resembled that which was characteristic of the laboratory samples to which mud had been added. These cores showed the presence of much foreign material such as quartz, feldspar and pyrite, and in some fossils could be identified. As it is impossible for a commercial cement to contain such materials and as the drilling mud does contain them, this proved that these cores had been badly contaminated with drilling mud. The type of fabric and the degree of hydration indicated that a large amount of water had been used in the cement mix, although in this case the evidence was not so decisive. The good cores showed the presence of foreign material but the amount was small and the mud instead

of being evenly distributed seemed to be more in the form of islands. It appeared also that less excess water had been used.

The cases cited are the extremes of very good and very poor cores. The cores of intermediate quality indicated that the excess of water and the extent of contamination was between these two extremes. Very few of the cores, either good or bad, indicated that carbonation had taken place to any material extent.

Conclusions from Laboratory and Petrographic Study

The laboratory work and the petrographic study both led to the same conclusions; namely, that the poor cores had resulted from the use of too much water in making the cement mixture and the subsequent contamination of this mixture with mud and not from the conversion of the cement or parts of it to carbonates. The laboratory work led further to the conclusions that the use of excess water is not in itself seriously objectionable provided nothing prevents the settling of the cement particles to form a compact mass at the bottom. Agitation with formation gas or contamination with mud will interfere with the settling. Where the amount of excess water used is small, even relatively large amounts of mud do not seriously weaken the cement, but with a large excess of water, small amounts of contaminating mud will produce a poor core. As it is impossible to eliminate mud contamination altogether, the amount of water used should be reduced to a minimum. In any case where the cement has settled, the sounder portions will be toward the bottom so that it is possible to get a satisfactory core from the bottom and an unsatisfactory one from the top; therefore the cores for inspection should always be taken as near the bottom of the hole as possible.

Field Observations

Having arrived at these conclusions from work in the chemical and petrographic laboratories, observations were made in the field to see whether these conclusions were substantiated by field practice and if so, to suggest a remedy.

All cementing for this company in the Gulf Coast area is done under contract, the contractor using the circulation method. The contractor furnishes the equipment for mixing the water and the cement and pumping it into the well as well as the man and helper to supervise the job and operate the machinery. The company furnishes the cement, the water and the additional labor necessary. As the contractors were specialists in this field and had considerable experience, their work previously had not been observed by this company in a critical light.

One of the first points studied was the use of excess water. It was found that the amount of water used was not measured, the operator

using as much water as he thought necessary to give the mixture the proper consistency for pumping into the well. As speed is essential and as a thin mixture is easier to handle and can be pumped more rapidly, the tendency was to use too much water. It was difficult to measure directly the amount of water used, for although the tanks from which the water was taken could be gaged, a large amount of water was used in flushing out the pumps, washing the machinery, and for purposes other than mixing with the cement.

The amount of water used was estimated by measuring the density of the cement slurry. By taking these density measurements at frequent intervals, it was found that the water content of the mixture was not uniform. If the cement hung up in the hopper or if the operator at any time did not have a bag of cement on hand ready to dump into the hopper, the water continued to enter the mixing vat although there was no cement to mix with it. As the capacity of the vat was small, any interruption in the cement supply meant that a very thin mixture was pumped into the well. The nonuniformity of the mixture was remedied considerably by providing two platforms on which the cement bags could be opened and two men to open the cement bags, thus insuring a steady supply of cement, and by impressing upon the operators the objections to nonuniformity. Positive displacement water meters were provided to measure the water actually mixed with the cement so that the water-cement ratio could be definitely determined.

It was found that in some cases the mud had not been circulated long enough to be sure that all accumulations of heavy mud had been removed from the bottom of the hole. Such accumulations of mud would have a tendency to contaminate the cement. Furthermore, the second plug between the cement and the mud was frequently omitted in order to save time. The trouble from mud contamination was minimized by having the mud circulated for a long period and insisting upon the use of the second plug. A special manifold for introducing the plugs into the casing without making or breaking any threaded joints was provided. This made the introduction of the plugs more rapid and convenient and reduced the time for cementing well considerably.

Observation revealed the fact that occasionally the cement operator allowed the pump to take suction faster than the cement slurry was prepared in the mixing vat and that the pump would draw in air and force it into the well. This was obviously objectionable because the air bubbles which were distributed through the cement would form voids to weaken the cement and make it less impervious. The operators were cautioned to keep the end of the suction pipe below the surface of the slurry at all times.

It was found that the cores were not always taken from the bottom of the cement that was left in the hole but after the importance of securing

cores from the bottom was explained to the drillers, little difficulty was observed.

When the work was started, accelerators were frequently used with the cement. It was found that the operator had considerable trouble in adding the accelerator uniformly to the cement mixture. As most wells were not being drilled under competitive conditions and extreme speed was not urgent, the use of the accelerator was eliminated entirely and all later cementing was done without it. However, a reburned and reground cement having a relatively short setting time was used in all later work.

Recommendations

As a result of this study of cementing in the Gulf Coast, the following recommendations were made: (1) As thin a mud as possible should be circulated before cementing to soften and remove the accumulations of thick heavy mud; (2) plugs should always be used ahead of and behind the cement; (3) as little water as possible should be used with the cement and the water-cement mixture should be uniform; (4) sufficient cement should be left in the hole to prevent the mud that follows the cement from approaching too near the casing seat; (5) cores for examination should be taken near the bottom of the casing to avoid the soft, unsound cement layer that may be near the upper part.

Ever since these recommendations have been put into effect, a poor looking core has been infrequent. There still remains, however, the problem of cementing in the hot formations encountered in deep wells. These hot formations are very troublesome but as yet the proper way of handling them has not been found.

Acknowledgments

The writer gratefully acknowledges the contributions made to this paper by W. T. Doherty, who carried on the early experimental work and assisted in the field observations; by George E. Cannon, who carried on the later laboratory work and assisted in the field observations; and by L. S. Brown, who carried on the petrographic study.

DISCUSSION

B. B. Cox,* New York, N. Y.—How much cement was recommended to be left in the hole?

H. H. Hill,† New York, N. Y.—At least 30 to 40 ft., and with deeper jobs somewhat larger quantities.

I. I. Gardescu,‡ Pittsburgh, Pa.—The permeability of the rock surrounding the cement affects to an appreciable extent the quality of the setting. Very unsatis-

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† Petroleum Engineer, Standard Oil Development Co.

‡ Petroleum Engineer, Research Department, Gulf Production Co.

factory results are obtained in attempting to cement a string of casing in a thick impervious clay horizon. This can be proved by performing a simple experiment. Two receivers are used, the first impervious, made of clay, the second porous, made of sandstone or plaster of Paris. Both receivers are submerged under water. A small amount of cement is poured in each one and allowed to set under water. The cement in the porous receiver will set in a shorter time and will be superior in quality to the cement placed in the impervious receiver.

MEMBER.—Does anybody know anything about shooting the cement in?

R. C. PATTERSON,* Taft, Calif.—We experimented in California on that considerably.

H. H. HILL.—Will you tell us something about cementing in the deep wells in California, where temperatures are as high as 200°?

R. C. PATTERSON.—The coldest water obtainable is used in preparing the cements, doing away with the quick-setting reagents they have been using and using a cement with slower initial set than is customary; practically going back, it is interesting to note, to a type of cement that was introduced in the industry in the earlier periods of cementing, with a low initial set.

H. H. HILL.—Is that an ordinary portland cement or is it a special mixture?

R. C. PATTERSON.—It is specially prepared. And talking about this type of cement to do away with the gas effect, they are using new equipment now; when they finish pumping in the cement, they have a back-pressure ranging from 1000 to 1500 lb. they will build up higher pressures as soon as they have equipment to handle it, and by so doing hope for more success.

C. P. PARSONS,† Duncan, Okla.—The problem in the Gulf Coast primarily was one of coring cement. In other words, when the double-tube core barrels were used, there was a tendency to grind up the cement. Consequently, every time a core was taken it could be crumbled in one's hands. They are now using the old basket type of core barrel for coring cement in that territory; that is very important. It appears best at present to core cement with a single-tube core barrel, or figure it as experimental with a double-tube core barrel.

Another important point about which a question was asked in this discussion, is the amount of cement to be left in the casing. There is no way in which that can be definitely determined, but we suggest that 10 ft. of cement be left in the casing for every 1000 ft. of casing, with a minimum of 25 ft. In that way the main body of cement is around the casing shoe. The laitance, or light fluffy cement usual on the top of a cement column, will be left in the casing.

Water meters are being tried to determine their suitability for measuring exactly the amount of water mixed with the cement. They meter the water that is injected into the mixer, and consequently the cementer can take a look at his meter and instantly see how much water he has mixed with a certain number of sacks. The status of the meter at present is experimental. There is a considerable load on a water meter doing this kind of work in the field, therefore such a meter should be rugged and constantly accurate.

Another important point is the uniformity of the mix. In the vacuum jet mixer the little jet nipple can be set to mix a certain minimum water-cement ratio, which can be as low as 3 gal. per sack, then the varying to higher ratios can be done by regulating the by-pass. There is a question as to just what is a practical water-

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† Field Engineer, Halliburton Oil Well Cementing Co.

cement ratio. Considerable experimentation with cement has shown that the lower the water-cement ratio the higher the strength, but we should look at the low water-cement ratio in relation to sub-surface conditions under which it is to be placed.

In the Gulf Coast very heavy muds are used. One well in the Hull field is circulating while drilling with 2300 lb. pressure per square inch. That is hardly conceivable, but it is true; the reason is that a heaving shale was encountered and a heavy drilling mud is used. Consequently, if it were decided to run casing in that well and cement it there would be 2300 lb. pressure to begin with in order to start the cement into the hole. Proper placing of cement behind the casing under such a condition calls for a higher water-cement ratio than ordinarily.

That brings up the question as to what is a practical range of water-cement ratios. It might be said that the maximum practical water-cement ratio would be the ratio at which water does not liberate freely from the neat cement, and that ratio is around 5½ to 6 gal. per sack. Consequently, if there is a tight hole neat cement with a ratio of 5½ gal. per sack of cement would be sufficiently dense and have sufficient strength to accomplish its purpose, and yet be fluid enough to be placed.

Water-cement ratios excessively above that would have a tendency to segregate into alternate layers of cement and free water. A minimum practical water-cement ratio is dependent on the workability of the mixture.

So far as pumping is concerned, a water-cement ratio slightly higher than 3 gal. per sack can be pumped. It is too difficult to start pumping at such a low ratio but it can be obtained after the pump has been started at a higher ratio. About 3.2 gallons per sack would be a practical minimum ratio. That is about 27 per cent. cement by weight; it makes a neat cement weighing nearly 18 lb. per gallon.

H. C. George,* Norman, Okla.—There is one thing I think should be added to our record. I heard it given at Ardmore, Okla. several years ago by Ed. Shell, who is a drilling contractor. Mr. Shell said, "In cementing the water string of casing in wells which were later standardized and completed by cable tools, I have found that the jarring action of the cable tools would loosen the last two or three joints of the water string of casing. This was due to the fact that the circulating mud left a ring of hard mud on the shale walls of the hole and upon the introduction of cement, the cement made contact with the hard mud rather than with the shale walls. Later this mud would loosen and cause the lower part of the water string of casing to swing loose in the hole and sometimes break loose, and in other cases cause the entrance of top water. In many wells drilled later, I corrected this difficulty by setting the water string of casing in the shell at the top of the oil sand."

R. C. Patterson.—In California, they use a dual system of meters so that if one meter fails after pumping is started, the second meter is left to check up with.

C. P. Parsons.—In California they are trying meters for measuring the displacement of fluid pumped in after the cement but we are using them for measuring the amount of water that goes into the mix.

R. C. Patterson.—With regard to the placing of plugs, it has been found that at the time of putting in the last plug, and before it reaches the top of the cement, the weight of the cement going down the hole draws in large quantities of air, thus creating an air pocket. That was quite a serious thing to contend with.

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Chapter X. Drilling Muds

Drilling Mud Practice in the Ventura Avenue Field

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(New York Meeting, February, 1930)

In some fields the problem of mud fluid is simple and easy of solution. But in the Ventura Avenue field the acquisition and disposal of good drilling mud is not the least of the problems that confront the operator. In fact, mud fluid in the Ventura Avenue field is a very important factor in the drilling of the wells. It is quite probable that many of the factors affecting mud in this field will not be found in most of the fields with which the reader is familiar. However, in the fields where the mud fluid causes no apparent problem it is probable that some of the points brought out in this paper could be used to economic advantage. In fields where caving and squeezing formations and high gas pressures are present, as in the Ventura Avenue field, it is believed that application of methods outlined will be of great assistance in drilling wells.

On account of the sandy nature of the formation and the lack of suitable shale bodies in the strata drilled through in the Ventura Avenue field, the wells make practically no mud during drilling. It is necessary therefore to supply drilling mud to the wells that will carry the drill cuttings to the surface, and also will "wall up" the drill hole and prevent the sandy formations from caving.

Mixing and Handling Mud Fluid

The clay used to make the mud fluid is obtained from a shale stratum in the upper Pico (Pliocene) formation found about a mile on either side of the field.

Since high gas pressures and caving formations were first encountered in the Ventura Avenue field and mud fluid was needed to combat them, the mixing of this mud fluid has gone through a process of evolution. First, the clay was mined and hauled to the derrick, where it was shoveled into the well and left for the churning action of the bit to mix into a mud in the hole. The next move was the construction of a mixer to mix the clay to a mud fluid which was pumped into the well. These mixing

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plants were constructed at central points on the leases and the mud was distributed from them to the wells in a pipe line system. Flumes were constructed from the wells to the settling basins to handle the waste mud from the wells. After this waste mud had been rid of sand, oil and gas it was pumped back to the mixers for reconditioning. This salvage of used mud greatly lessened the amount of dry clay necessary to keep up the mud supply and also lessened the expense of constructing additional sumps and settling basins to hold the waste mud.

The hauling of the mud from the mine to the mixer and the upkeep on several mixers and pumps was expensive, therefore it was finally decided to construct a central mud-mixing plant at the source of the clay and pump the mixed mud from there to the drilling wells. Each of the two major operators in the field (Shell Oil Co. and Associated Oil Co.) now has its own mud-mixing plant at the source of supply. The mud is mined, as before, with steam shovels, as it is too hard to mine hydraulically or with scrapers.

These two plants are similar, varying only in detail. The best points of each plant will be described. One is steam driven and the other electrically driven.

These plants are constructed on the side of a hill on several terraces. The clay is hauled a short distance in dump trucks and dumped into a large hopper leading down to the mud mixer. The clay runs from the hopper to a crusher, which crushes the mud into small clods about the size of a walnut. One of the plants has no crusher, so that the clay is crushed in the mixer, thus increasing wear and tear on the mixer and reducing the plant capacity.

The mixers at one of these plants are made from old boilers. A shaft 6 in. in diameter is used in the mixer; the part upon which the paddles are mounted is square, with a groove planed to receive each paddle. The paddles are fitted to the shaft, the two halves of the paddle being bolted one on each side of the shaft and then spot-welded together. The paddles are so constructed that the thrust set up by one paddle is counteracted by the thrust of the adjacent paddle. Stuffing boxes of special design are fitted to the ends of the mixer. The ends of the square shaft are turned down 6 in. in diameter and the shaft is supported by babbitt bearing. The mixers and bearings are mounted on reenforced concrete piers.

The clay is hydraulicked into the mixer with water or waste mud which has been pumped from catch basins to a storage tank. The mud from the mixer flows through settling tanks and then to the storage tanks by gravity. The settling tanks catch the particles of sand and only the best mud is run to the storage tank.

The mud is mixed so that the mud fluid has a weight of about 81 to 85 lb. per cu. ft. (sp. gr. 1.30 to 1.36). This is the heaviest mud made

from Ventura clay that can be handled efficiently by the pumps. If necessary, this mud is thinned at the well to the weight desired for operations going on at the time. In special cases heavier mud fluid is mixed for a well that is gassing. This mud is secured by rerunning the ordinary mud through the mud plant and securing mud weighing 90 lb. per cu. ft. (sp. gr. 1.44).

The pipe line system for mud fluid is routed over the various leases to each drilling well. A 500-bbl. mud-storage tank is placed at each drilling well. Whenever it is necessary to change the mud being used in drilling a well, fresh mud is supplied from this tank. The tank is then refilled from the main mud system, the mud being pumped from the central plant. When the mud has become full of sand and possibly oil and gas, it is dumped into a flume and carried to one of the settling basins.

During the travel of the waste mud through the flumes to the settling basins most of the gas escapes from the mud. Any gas that remains in the mud will rise to the top while the sand is settling. The oil collects on top during this time and is either burned or drained off from time to time. Pumps are mounted on scows and are floated in these large settling basins. The discharge line and steam line are run from the bank of the settling basin to the scow on floats. Swings are constructed in the pipe line at the bank so that the scow can be moved upon the mud without setting up undue stresses in the lines. After most of the sand has settled out of the mud in the settling basin, the mud is pumped back to the central mud plant to be re-used.

It has probably already become apparent that the mud goes through a rather definite cycle: (1) the so-called waste mud from the settling basin is pumped to the central mud mixing plant and thickened by adding fresh clay from the chute; (2) it is pumped to the well where it is used; (3) it is discharged from the well to the settling basin. This cycle may be continued until the sand content of the mud in the settling basin becomes so great that it is no longer serviceable.

Drilling Mud Fluid

Mud fluid used in the Ventura Avenue field for drilling purposes is generally carried considerably heavier than in most other fields. The sandy stratas drilled through must be kept well mudded or the hole will cave. For this reason mud weighing less than 75 lb. per cu. ft. (sp. gr. 1.20) can not be used, as it will not properly "wall up" these sandy formations.

Revolving sand screens were used on two wells some years ago and because it was necessary to add water to keep the screen clean the weight of the mud fluid could not be kept above 70 lb. per cu. ft. (sp. gr. 1.12) which caused serious caving in both holes.

Mud fluid weighing from 75 to 81 lb. per cu. ft. (sp. gr. 1.20 to 1.30) has been found to be the best for drilling purposes in this field, the weight depending on the amount of sand in the formations through which drilling is progressing. Lighter mud, as explained, can not be used in Ventura Avenue field, though in other fields mud weighing even less than 70 lb. per cu. ft. might be used with good results.

Mud weighing more than 81 lb. per cu. ft. will retard speed of drilling and prevent cuttings from dropping out in the settling ditch. Pump pressures varying from 100 lb. with 8-in. drill pipe at shallow depths to 1400 lb. with 2½-in. drill pipe below 7000 ft. are required to circulate this mud.

Because heavier mud must be used to drill the wells this mud does not drop all its cuttings of sand and shale particles in the settling ditches; consequently the mud being used contains a high percentage of sand. Besides causing considerable wear on the pumps sandy mud often causes the drill pipe to stick, and invariably when a twist-off occurs it cannot be pulled from the hole with the overshot, as the sand has settled around it. Sometimes frozen drill pipe could be loosened by circulating or spotting oil, if circulation could be secured around the "fish," but many times expensive washing over and cutting jobs, and in some cases even side-tracking jobs, were necessary.

Since the completion of the central mud-mixing plant, which insured a greater supply of new or reconditioned mud to the wells, thus allowing mud in the well to be changed oftener, drill pipe does not freeze so often, and when twist-offs occur it is often possible to pull the fish with an overshot without resorting to washing over.

With the system of allowing mud to settle in large settling basins, the sand settled out so slowly that considerable mud also settled to the bottom. This not only caused the loss of a great quantity of good mud but also filled up the large settling basins very quickly. As these large settling basins are very costly to build because of the very rugged topography, and places to build them are becoming scarce on the lease, three methods are now being tried in an effort to solve this problem. The first two do not contemplate the elimination of the sumps but expect to remove the sand from the mud before it is returned to the settling basins, so that this mud may be returned immediately to the mud-mixing plant after the oil is separated from it. This will eliminate the long settling period and practically the entire amount of mud can be returned to the mud-mixing plant for reconditioning, thus eliminating the loss of good mud and preventing, to a great extent, the filling of the settling basins.

The first process makes use of a centrifuge of special design. This machine was set up at a well and it was intended to take the sand from the mud at this well. An 8-mesh vibrating screen was installed above

the centrifuge and a flume built from the screen to discharge into the centrifuge. The centrifuge revolved at 600 r.p.m. The mud was pumped from the suction tank and discharged upon the screen, where all large substances were separated from the mud so that the nozzles in the centrifuge would not become clogged. This machine took out a large part of the sand and saved considerable wear on the mud pumps in the rig. Also, two fish were recovered from this hole with the overshot and fish were found loose in the hole in both instances. However, this machine wastes some mud. Tests are still being conducted and definite information is not yet available as to its actual practical value.

The second process makes use of a 40 to 60-mesh vibrating screen, which consists of a channel iron frame upon which a steam turbine is mounted to operate the vibrator. The screen is of monel metal cloth, mounted on bars which are attached to the vibrating mechanism, which is capable of vibrating the screen at 1600 vibrations per minute. The screen is set at an angle of 20° to 30° and the mud, as it circulates from the well to the suction pit, flows upon the metal cloth, which vibrates rapidly. This vibration forces the mud through the screen, whence it is returned to the suction pit and the sand particles bounce over the screen and are discharged from its lower end. The sand is separated from the mud so completely that only a very small part of the mud formerly used at a well is now necessary. Only about 600 bbl. of mud have been used in six weeks of drilling.

Both these processes will also remove gas from mud in a satisfactory manner. Though these machines are now installed at individual wells, larger units could be made to treat waste mud just before entering the settling basins, so that the mud could be pumped immediately from the settling basins to the mixing plant before any of the mud settled to the bottom of the settling basins.

The third method, in which only a small experimental plant has so far been in operation (large plant now under construction), contemplates the entire elimination of large settling basins and expects to return mud of desired weight directly to the wells for immediate use without returning the mud to the mixing plant for reconditioning and addition of weight. This plant can be used in conjunction with the two other methods described, and if it operates as well as it is hoped it will eliminate a vast amount of mud mixing.

The last method has been an experiment with a classifier and settling tank or thickener. The waste mud from the wells is discharged into a classifier such as is used in certain mining processes. The mud is then diluted with water from the top of the thickening tank, until the classifier is able to extract practically all of the sand, and the gas allowed to escape from the mud. The diluted mud, free from sand, is then pumped into the thickening tank, where the mud settles to the bottom of the tank and

the oil and water are drawn off from the top. The mud is pumped from the bottom of the settling tank weighing as high as 80 lb. per cu. ft. This weight can probably be increased. This mud contained only a small percentage of 200-mesh sand. The operation of the large plant will be watched with great interest.

Naturally, there will be a certain amount of mud loss in the operation of these systems and there will still be a certain amount of loss of mud in wells during drilling. However, with the successful operations of these or other similar systems a great saving will be made in the amount of new mud fluid that must be mixed, and a better mud fluid will be available for the drilling of wells.

Use of Mud in Running Casing

Before running casing, the hole is conditioned with mud weighing about 75 lb. per cu. ft. The mud cannot be thinned below this weight as the walls of the hole are apt to cave. Heavier mud than this has a tendency to settle if not kept in motion. In running long strings of casing from 20 to 30 hr. elapse from the time the drill pipe is pulled from the hole until the casing is run to bottom. If the mud has settled to any great extent it will be difficult to get the casing to bottom.

The addition of aquagel or other substances, such as Mud-it, hydrated lime, or rotary gel, that will tend to jelly the mud will help materially in keeping the mud in suspension, but unless the mud must necessarily be carried heavier than usual to keep a hole that has a bad caving condition from sloughing, ordinary mud weighing 75 lb. and free from sand has been found satisfactory. Several years ago in running long strings of casing, when the quality of mud was not as good as it is now, it was the practice to put several hundred barrels of oil into the casing. At intervals, when the pipe became logy, some of this oil was pumped out to prevent the casing from sticking. Though this method was successful it has now been discontinued except in extremely long strings of casing with a large amount of friction or in tight hole, as it was found that with mud that is free from sand it is not necessary, and practically all casing is now successfully landed on bottom without the use of oil.

Mud for Loss of Circulation

When circulation is lost a thick mud that will plaster the walls of the hole and fill the cavities is desired. The best substances for regaining circulation are believed to be aquagel, rotary gel, hydrated lime, bentonite and Mud-it, which will thicken and have a tendency to jelly the mud. Though aquagel is the only substance that has been used here, the other substances are said to act with somewhat the same results. The chief requisite in the use of aquagel is to be sure that it is properly mixed so that every particle comes in contact with water, so that it will form a

jelly. If it is not thoroughly mixed it will form in lumps which have an outside coating of jelly and will be dry in the center. The most efficient way to mix it is in a cone-shaped hopper with a water or mud jet in the bottom. The powdered aquagel is fed into the top of the hopper and is thoroughly mixed with mud or water coming through the jet. Bentonite, rotary gel and hydrated lime would be mixed in the same manner, but Mud-it is an oily fluid that is added directly to the mud fluid at the well, either in the ditch or suction pit, and creates a jellying action in the mud. When a hole has complete loss of circulation it is well to pump mud with the addition of some jellying compound into the hole and allow the hole to stand unmolested for 12 to 24 hr. However, if there is only a partial loss, the jellying substance may be added to the mud as drilling progresses.

Heavy minerals have also been added to the mud in attempts to recover lost circulation but only with partly satisfactory results.

The swelling characteristic of beet pulp and cotton-seed hulls has prompted their use to fill cavities in the hole. The pumping of these materials into the hole has sometimes been responsible for the recovery of lost circulation.

A 10 to 15 per cent. aquagel mix with water mixed with cottonseed hulls has been found to be very effective for spotting in a well for lost circulation. This mix is placed in the hole at the point of lost circulation and is allowed to set for about 12 hr. It seems that the cottonseed hulls and the aquagel form a mat on the walls of the hole that is not broken down as easily as that of an aquagel and water mix.

Mud Fluids for Squeezing and Caving Formations

Squeezing and caving formations are sometimes confused and believed to be the same thing. It is true that it is difficult and often impossible to differentiate between the two. Caving formations can sometimes be "walled up" by thickening the mud, but if a bad caving condition is present it can probably be more quickly and permanently relieved by the addition of jellying substances mentioned under muds for loss of circulation, as they will add to the mud an additional plastering quality.

However, if formation is squeezing in, thus reducing the diameter of the hole, the thing to do is increase the static weight of the fluid column so that the static pressure will tend to keep the hole from squeezing in. The addition of jellying substances which have lower specific gravity than the clay used will not help this condition, as the resulting mixture will be lower in specific gravity than pure clay mud. Squeezing formations can sometimes be overcome by the addition of heavy minerals or salt to increase the static head of the fluid column. As heavy minerals are more universally used to combat high gas pressures, they will be discussed more in detail under that head. They are used similarly to

combat the squeezing hole problem. Salt has been used to a slight extent to increase the weight of the fluid column, with some degree of success in combating squeezing holes. Salt dissolves in the mud fluid and increases its weight without thickening the mud to any extent. Salt, however, forms a slight froth in the mud, probably due to some chemical reaction between the salt water and certain substances in the Ventura clay which in the presence of gas is greatly increased so that it has not been successfully used in combating high gas pressures. This chemical action may be greater or less in other muds and if it is very great will probably lighten the fluid rather than increase its weight, if the gas formed is retained in the mud.

Muds for Combating High Gas Pressures

Pure clay mud fluid without the addition of heavy minerals, weighing 90 lb. per cu. ft. (sp. gr. 1.44) is effective in controlling ordinary gas pressures. However, when heavier mud is needed the addition of heavy minerals to the mud is advisable.

Though the authors have observed the use of mud fluid mixed from Ventura clay without the addition of heavy minerals weighing as much as 94 lb. per cu. ft. (sp. gr. 1.5), this mud was so thick that it was with great difficulty that pumps were able to handle it. Mud with the addition of heavy minerals weighing as much as 106 lb. per cu. ft. (sp. gr. 1.7) could be handled more easily than pure mud fluid weighing 94 lb. per cubic foot.

Mud fluid that with the addition of heavy minerals weighs 100 lb. per cu. ft. (sp. gr. 1.60) is sufficiently heavy to control any gas pressures yet encountered in the Ventura Avenue field if the gas is completely mudded off, before attempting to come out of the hole with the drill pipe.

It may even be advantageous, if only 90 lb. mud fluid is desired, to use some heavy mineral, as a much thinner fluid may be obtained than by the use of pure clay mud. Thus, 80-lb. mud fluid may be raised to 90 lb. by the addition of 18 lb. of heavy mineral to 100 lb. of mud fluid. This fluid is more easily handled by the pumps and if it is used for drilling it will drop cuttings more easily. However, it is not thought advisable to mix heavy minerals with mud fluid weighing less than 80 lb. per cu. ft., as there will not be enough clay in the mud to keep the heavy mineral in suspension.

Practically all of the heavy minerals now being manufactured for use in drilling muds have a base of either hematite or barite, though some contain considerable magnetite. There are so many trade names for these substances that they will not be mentioned. For use in mud fluid there is generally added some "suspender" to the base material, that will tend to keep the heavy mineral in suspension. The chief of these suspenders are bentonite, or other clay, and aquagel.

Heavy mineral compounds for use in mud fluids have an approximate specific gravity of 4.0. One of the chief factors in heavy mineral compounds is the fineness. The material must be ground very fine or it will settle too quickly. The material should be ground so that 98 to 99 per cent. will pass through a 200-mesh screen.

Conclusion

Attention to mud fluid in the drilling of oil wells repays the effort and expense it entails. We believe that aside from the big saving on pumps and pump parts, the proper attention to condition of mud prevents possible blow-outs, reduces amount of frozen strings of drill pipe and casing, and when fishing jobs occur, increases by far the chances that these fishing jobs will be brought to a fast and successful conclusion. It may be argued that the lessened amount of frozen drill pipe and casing, and the greater ease with which lost drill pipe is recovered from the hole, is due to the drilling of straighter holes than heretofore. There can be no doubt that the straight hole and better equipment of all sorts are great aids to keeping out of difficulties, but also it cannot be denied that mud fluid of proper weight and consistency and free from sand is entitled to a large share of the credit for the drilling of deeper and deeper wells in the Ventura Avenue field, with more certainty of success and in a more economical manner.

DISCUSSION

R. C. Patterson,* Taft, Calif.—This study brings a certain incident to my mind An operator's superintendent in Kettleman Hills was having considerable trouble and expense in securing a satisfactory mud in the hills. A mud freighted from the Mohave Desert into the field proved to be very expensive. An expert from a Los Angeles basis field was assigned to selecting satisfactory mud. This man upon learning of the new problems confronting the operators of this field said he had never heard of such a thing, and threw up his hands. In this field it is necessary that one secure the proper ratios. For instance, not more than 5 per cent. of aquagel can be used because with the enormous gas pressure it causes the muds to froth much more readily, and now large quantities of hematite and barite are used. That is due to the fact that it is necessary to have these heavier specific gravity ingredients because the shales that are drilled through have such a heavy weight that they have to be kept buoyed by a heavy gravity mud.

Another interesting question in the Kettleman Hills is the effect mud fluid will have on the oil and gas formations during this period of shutdown. Some operators thought it would be more economical to shut the wells in just after encountering the prolific horizon, but in this day and age of speed and power they are afraid that when they open up the wells the other fellow would have the drop on them. A great number of wells have been drilled through the oil formations, penetrating the prolific horizon from 100 to 1000 ft. One operator decided to blow the well to clean it of heavy mud fluid and replace it with a lighter mud and shut the well in. The well was allowed to blow for two days sufficient lapsing to allow all the

* Supervisor, Oil and Gas Operations, U. S. Geol. Survey.

mud fluid to be removed. We were much surprised to find that during the last 24 hr. of the flow practically pure barite was blown out. The other fluid substances had separated and the barite had evidently penetrated the sand and was the last to leave.

H. H. Hill,* New York, N. Y.—What weights are they using in Oklahoma City now?

C. V. Millikan,† Tulsa, Okla.—They run from 9½ to 10½ and over 11 when gas sand below 6000 ft. is being drilled.

R. C. Patterson.—Another handicap in these deep drilling areas is the use of different types of mud pumps. In Kettleman Hills, where electrically propelled pumps are used with air chambers attached, those chambers become locked with gas and make it hard to circulate the mud fluid and thus cause loss of time. An average weight of mud fluid in Kettleman Hills gas zone is about 92 to 94 lb. per cubic foot.

F. J. Fohs,‡ New York, N. Y.—This is a little foreign to the discussion, but recent experiments we have had in the Gulf Coast might be of interest. In drilling through salt in the salt domes, we found that the use of salt was much more effective than the use of fresh water.

H. H. Hill.—I know one place where salt solutions are being used, because they are sampling the salt. In order to prevent the salt from dissolving, they circulate a saturated solution.

F. J. Fohs.—We drilled through 900 ft. of salt in this manner and went back out into the formation, which is rather unusual.

B. B. Cox,§ New York, N. Y.—Has aquagel ever been used in connection with brine solutions to hold mud, barites and hematite in suspension?

R. C. Patterson.—A certain percentage of it is used continually. If too much of the aquagel is used it becomes too stringy. In circulating previous to cementing, it comes out stringy.

B. B. Cox.—My question was: With a brine solution to start with, has aquagel been tried to keep the weighting material in suspension? For instance, to prevent caving in a salt series in which gas pressures are expected.

F. W. Hertel and E. W. Edson.—Due to the scarcity of fresh water, sea water has been used for mixing mud in the Rincon field, 8 miles north of Ventura on the Pacific Ocean. This mud fluid is accompanied by a slight amount of froth and settles more rapidly than mud fluid mixed with fresh water but has been satisfactory as an ordinary drilling fluid. The addition of 1 to 3 per cent. aquagel has produced a mud fluid that is very good.

Regarding the use of aquagel with brine solutions, we are informed by a representative of the California Talc Co. that laboratory experiments show that there is a very little difference between the action of aquagel in fresh water and in a saturated salt solution. The aquagel remains in suspension practically as well with salt water as with fresh water. The use of aquagel in a strong brine or saturated salt solution has not been tried in actual practice, to our knowledge.

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† Production Engineer, Amerada Petroleum Corpn.

‡ Consulting Oil Geologist.

§ Near East Development Corpn.

Chapter XI. Corrosion

Review of Oil-field Corrosion Problems for 1929

By L. G. E. Bignell,* Tulsa, Okla.

(New York Meeting, February, 1930)

Surveying what was done in 1929 in meeting problems of oil-field equipment corrosion, one is struck by the fact that fewer meetings were held for discussion of these problems and fewer papers written than in any year since the subject engaged the attention of petroleum engineers. This does not mean that progress has not been made, for a great deal actually has been accomplished. Recommendations that accompanied field reports have been put into actual trial and some results obtained are gratifying.

The type of papers prepared also has undergone a change, for they now deal with things accomplished rather than recite damages and suggest possible remedies. Some of the most notable work pointing the way for future solution of many pipe line problems is that done for the U. S. Bureau of Standards by Dr. K. H. Logan and Dr. Gordon N. Scott, dealing with tests of pipe coatings and reports on soil conditions. Many facts of great importance have been isolated and defined by these two men, not only indicating what may be done in some instances to retard corrosion, but showing that things formerly considered of importance have little bearing apparently upon the practical results.

All-aluminum Storage Tanks

In April, 1928, an all-aluminum 500-bbl. field storage tank was put into actual field use in Crane County, Texas, together with another tank of the same capacity but made with steel bottom and lower section of side sheets and aluminum upper ring of side sheets and deck. In April, 1929, after a little over one year's use these tanks were opened and examined by a group of engineers and chemists. The results of the test were enlightening.

Other tanks made entirely of steel and used in the same battery with the two test tanks had some of their side and bottom sheets destroyed by corrosion in six to nine months, but the all-aluminum tank was in actual use for 18 months before holes were found corroded through the bottom, when the tank was examined for a second time in September, 1929. This field test of the aluminum tank confirmed the already known

* Petroleum Engineering Editor, *Oil and Gas Journal.*

fact that there is no stable combination of that metal and hydrogen sulfide or any of the sulfur compounds found in the oil and water as produced by these wells.

Aluminum is inert in the presence of hydrogen sulfide gas, or sulfur-bearing crude oils and therefore should be of definite value for the construction of equipment that can be fabricated from it provided the finished article has sufficient tensile strength for its required duty. Decks for large tanks in which sulfur-bearing crude oils are stored might well be made of aluminum sheets for the deck and side sheets of this aluminum test tank have not shown any signs of corrosion up to this time and apparently will last indefinitely.

Failure of the bottom is attributed to the presence of iron sulfide scale introduced into the tank through the mistake of an employee who inserted a gaging well made from 26 gage sheet steel into this tank and as this thin metal very quickly corroded, the iron sulfide produced by the reaction fell to the bottom of the tank in pieces of appreciable size. The iron sulfide scale and the aluminum in contact in an electrolyte formed from the water in the bottom of the tank set up an electrochemical action that caused the aluminum to go into solution and in 18 months several holes were eaten through the bottom sheets.

The obvious method of overcoming this particular condition is to keep iron and steel parts out of contact with the aluminum equipment, and if this is done iron sulfide scale in appreciable quantities will not be introduced into the aluminum tank or other equipment.

The composite, or half-steel and half-aluminum tank did not handle hydrogen sulfide gas in any appreciable quantities. The oil that passed through it had previously been heated to a temperature of about 180° F. and in this way had lost much of its objectionable sulfur contents, so it is difficult to draw any direct comparison between these two test tanks, other than to say that the composite tank was apparently as good after 18 months of use as when it was installed.

Field Tests on Aluminum and Steel Tanks

In May, 1929, the U. S. Bureau of Mines established a field laboratory at Borger, Texas, for the purpose of observing the action of crude oil, water and hydrogen sulfide gas from wells in that area upon aluminum and steel tanks. The battery consists of one 500-bbl. all-alluminum receiving or treatment tank, two 250-bbl. all-aluminum and two 250-bbl. all-steel pipe line tanks—five tanks in all.

The test will not be completed for some time, but it is understood that salts in solution in the water entering the treating tank have dissolved aluminum pipe that was used in the form of a steam-heating coil within the tank. In the light of previous experiments with aluminum in contact with hot water carrying salts in solution these results could have been

predicted, but this reaction should not reflect upon the work done in the Crane County test.

If equipment is required to handle oil or water containing salts in solutions that make a mixture destructive to aluminum, the logical procedure is to neutralize or remove those salts before the liquid is introduced into the aluminum vessel.

Aluminum Foil—Protective Coatings

Aluminum foil has been used in several tests during the past year and Dr. Stanley Gill presented a paper before the American Petroleum Institute meeting in Chicago early in December on this subject.[1] While this material seems to present many interesting possibilities, the principal problem to be solved in connection with its use is the preparation of adhesives that will hold it in place under varying conditions. Some types of cement or paste have been used with success, but the time element has been relatively short and the final results will not be known for some time.

Protective coatings to retard corrosion are still being recommended and many of them give good results under actual field conditions, but experience and detailed knowledge of the entire problem are required in the selection and application of such coatings.

Much has been learned along these definite lines in the past year and progress is being made by the process of elimination. The industry is coming to know what types of materials should not be used and in this way the field of vehicles and body elements for protective coatings is being narrowed down, with the result that proven materials are being used with much better success.

Investigations on Corrosion

The metallurgist has been by no means inactive. In a lecture before the Conservatoire des Arts et Métiers in Paris, Albert Portevin stated that at least 4000 investigations on corrosion had been made and reports published, not all in the past year, but all available for study at this time.

In his opinion if the choice of a noncorrosive substance were not influenced by cost, platinum offered an ideal solution. If mechanical properties could be ignored, glass and ceramic products solved most of the other problems connected with corrosion. If, on the other hand, the lowest priced material must be used, cast iron would serve. If superior mechanical properties were essential, ordinary steel conformed to most of the requirements.

Heterogeneous structures in the metal encourage certain electrical action which accelerates corrosion. On the other hand, the surface layer formed by the corrosion itself retards further action and may even completely arrest the chemical attack on the metal. All industrial metals (except perhaps the precious metals) are chemically unstable in the

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[1] S. Gill: Aluminum and Its Alloys as Corrosion-resistant Materials in the Oil Industry. *Proc.* Amer. Petr. Inst., Chicago, December, 1929, Sec. 3, 142.

presence of oxygen and acids, and their only chance of survival is offered by the protecting coat formed during early corrosion. The most interesting metals showing these phenomena are aluminum, nickel, cobalt, and, in a lesser degree, copper and steel. Metals in themselves rapidly attacked may become passive (*i. e.*, have a protective oxide formed) if certain metals (chromium, silver, molybdenum, vanadium and tungsten) are added to them.

Chromium Steel

Chromium steels, termed stainless, constitute an immense advance in the pursuit of corrosion-resisting alloys. In M. Portevin's opinion their introduction marks a veritable revolution in the use of metals, not only for current industrial requirements, but also for the needs of important chemical processes.

These steels fall into three categories: (1) ferrites with very little carbon, which are malleable and are employed without heat treatment; (2) martensites, nonmalleable and used for hardening, and (3) austenites, solid-solution alloys of iron, chromium, nickel and carbon, which after quenching are still malleable.

Heterogeneity and Other Factors

In all practical applications heterogeneity must be avoided. This principle would require the minimum number of alloys in a particular system, at least where they come in contact, and where such a joint is exposed to the corrosive conditions. Extreme care therefore must be taken in fabrication, welding, riveting, or other methods of assembly which lead to inequalities of composition. Other important factors to be watched are the temperature and pressure of the corroding medium, its aeration, and the superficial condition of the metal used.

Reports of specialists in many arts and industries are available for those who care to make use of them. Those who are interested in corrosion are being educated in the subject through open forums and a growing volume of literature. They are forewarned and hence forearmed.

Changing Conditions Bring New Problems

With field men and operatives in refineries and other branches of the petroleum industry better trained to analyze conditions as they develop and to meet them if they become dangerous, there is less discussion of corrosion problems for the simple reason that there is a steadily diminishing necessity of enlisting the counsel of others. That is to say, conditions that used to be problems are no longer problems, leaving fewer things in this field to be talked or written about.

In the meantime a limited number of technical men continue their research work, upon the basis of which forward strides will be made. By the time the next generation of workers is busy with its problems again it will be found that the solutions now offered will not fit. So the cycle of new investigations begun and completed keeps on.

Petroleum Economic Review for 1929

By Warren A. Sinsheimer,* New York, N. Y.

(New York Meeting, February, 1930)

Probably there has never been a year during which the petroleum industry expended so much effort as in 1929 in an attempt to rectify its ills. Eventually good will undoubtedly result, but as yet there have been no marked changes from the unhappy conditions familiar to all. Throughout the year remedies were sought that would cure the long-existing troubles of overproduction and waste.

Proration of production and voluntary curtailment of output, for a short time considered the means for stability, not only failed but contributed to further waste and created a false sense of security. It encouraged a high rate of field development, weakened the economic structure by excessive development of newly discovered reserves and absorbed large sums of capital yielding meager or negative return.

The manufacturing of gasoline by refiners without regard for market requirements furthered the unsatisfactory condition by falsely stimulating the demand for crude and placed on the market an oversupply of finished products, particularly gasoline. The marketing section of the industry has made progress by its adoption of the Code of Ethics as promulgated by the Federal Trade Commission and by the formation of an Export Association.

The year 1929 opened not only with a current supply of oil exceeding demand but with an additional daily shut-in and potential supply variously estimated at from 3,000,000 to 5,000,000 bbl. This situation stimulated the industry, through the American Petroleum Institute, to attempt to work out an economically sound solution which would further conservation by bringing supply and demand into closer balance.

Production Control

After a thorough study of producing conditions, the committee of the American Petroleum Institute had for its recommendation that the production of crude oil in 1929 be held in check to an amount equal to that produced during the year 1928. The Federal Oil Conservation Board heard the appeal of the American Petroleum Institute and referred the matter to the Department of Justice. It was ruled that neither the Federal Oil Conservation Board nor the Department of Justice had the

* Land and Oil Production Dept., Henry L. Doherty & Co.

power to approve the plan. As a consequence, the activity on the part of the American Petroleum Institute subsided and the task of production control was left with the producers and the various state regulatory bodies.

In June, a meeting called at the suggestion of President Hoover was held in Colorado Springs, to discuss the plan of state compacts as offering a workable plan for the conservation of oil production. This conference failed to produce any tangible results. Thus the only conservation measures taken during the year were those developed within the individual producing states where state regulatory bodies acted from time to time as particularly aggravating cases commanded attention.

The California State Legislature passed a Gas Conservation Law, the operation of which has been delayed by legal action. In Oklahoma and Texas state regulatory bodies have from time to time issued proration orders curtailing the output of several of the flush fields. In some flush fields there have also been voluntary curtailment agreements. In a number of instances various companies have pooled acreage to insure a more orderly development and lessen waste. In most instances where proration occurred speed of development was not lessened. As a result the potential and shut-in production has increased. Unnecessary wells were drilled only to be drastically prorated or entirely shut in. The industry continued to invest capital that cannot currently produce an earning and at the same time continued a vigorous drilling campaign which, added to the already high potential production, further weakened the economic structure.

Unit Operation

Exactly five years ago, on Feb. 18, 1925, Henry L. Doherty read a paper before the A. I. M. E.,[1] entitled "Suggestions for the Conservation of Petroleum by Control of Production." At that time the industry did not take kindly to Mr. Doherty's plan, but he sowed the seed of a new thought—unit operation of oil pools. The seed has been germinating slowly. Gradually, proponents of unit development have come forward, each with his own scheme; few, if any, giving much credit to Mr. Doherty. Recent enunciations by various other leaders in the industry, as well as plans formulated by the American Petroleum Institute inaugurated during the past two weeks, indicate that at least the basic principals of the Doherty unit development plan will become a reality.

Increase in Stocks

Despite all the efforts put forth and despite a consumption of petroleum products greatly in excess of that which had been looked for, the year 1929 closed with an increase of 9.61 per cent. in stocks of crude oil,

[1] Production of Petroleum in 1924, A. I. M. E. (1925) 7.

an increase of 29.41 per cent. in stocks of gasoline, and with the unprecedented total of 688,000,000 bbl. of all petroleum stocks above ground.

While conditions in the producing branch were admittedly unsatisfactory, part of the overproduction can be attributed to refineries operating in excess of market requirements. This uneconomic procedure artificially stimulated the demand for crude and worked to the disadvantage of the producer and refiner alike.

As will be recalled, the year 1928 was a fairly prosperous one for the refining and marketing branches of the iudustry. In 1927 the law of supply and demand developed an extremely low price for gasoline, with the result that refining operations were drastically curtailed in the winter of 1927–28. The sharp increase in gasoline demand in 1928 was for a short while overlooked by the refining industry. There was no overproduction of gasoline in 1928 and as a result a fairly satisfactory economic condition existed for this commodity. These same economic conditions were not existent in the winter of 1928–29 and are being ignored again at the present time.

Increased Recovery of Gasoline

Significant in providing for demand of motor fuel is the trend of increased recovery based on a unit quantity of raw material. The increase in recovery of natural-gas gasoline and the marked expansion of cracking facilities are important factors combining to reduce the amount of crude necessary to produce a barrel of gasoline. This trend has been pronounced during the past five years. A study of statistics reveals that during this period the volume of crude necessary to produce one barrel of gasoline has decreased by 22 per cent. It is apparent that increases in gasoline demand must be discounted in gaging the necessary crude supply to meet it. Through the medium of cracking facilities and large stocks of fuel oil on hand, it is not only possible but highly probable that this trend will continue. In this connection it is interesting to note that in order partly to rectify our present economic gasoline situation runs to stills in 1930 can be reduced by 2 per cent. from the 1929 level and adequately meet a 10 per cent. increase in demand.

As refining facilities are adequate to meet current demand even at the height of the consuming season, it is no longer necessary or sound to carry inventories of gasoline in excess of working stocks. This, together with the ability to forecast demand closely over long periods, places the manufacturer in a position of flexibility where he can make the most of his opportunities.

Ethical Standards

The principle of fair trade practices as interpreted by the Federal Trade Commission is the basis of the Code of Ethics now finding applica-

tion in the marketing of petroleum products. The adoption by responsible units of the ethical standards embraced in the Code has promoted a healthier competition in the domestic marketing field. The export movement has been benefited by the functioning of the Export Association. However, the battle for gallonage still goes on.

Trend to Complete Integration

During the past year there has been a further development in the trend toward complete integration. This movement has been marked by several mergers already completed and others in process of negotiation. The industry has been making a strong effort towards reducing costs and it is apparent that it realizes that part of its salvation lies in efficiency in all branches.

The Immediate Future

The unsatisfactory condition that obtained throughout the year 1929 has already been reflected in 1930. Crude oil prices have been reduced since the first of the year and the wholesale price of gasoline is at a low postwar mark. Stocks of both crude oil and gasoline are at an all-time peak. In a large measure, above-ground stocks do not portray the real situation. In Kansas, Oklahoma, Texas and California there are numerous fields either partly or fully developed under the 1928–29 system, prorated to but a small percentage of their actual capacity to produce today. These developed but prorated pools constitute a stock of crude petroleum which should be given consideration in the same category as above-ground storage.

The drastically curtailed daily production is in excess of current requirements and only slightly under the peak of midsummer demand. So far the industry's attempt to regulate itself without drastic price readjustments has been unsuccessful. The immediate future is difficult to forecast. The petroleum industry is an essential one and an essential industry can only prosper at a profit to the operators in it. There is some solace in this thought.

Statistics

There is appended to this paper a tabulation and a set of charts portraying the principal statistical changes that occurred in the industry during 1929. In some instances a short discussion accompanies each set of figures or charts.

Table 1 sets forth statistics of crude and refined petroleum in above-ground storage. Included in the tabulation of refined stocks is the item of California crude oil below 20°, statistics for which cannot be segregated from those of fuel oil.

TABLE 1.—*Total Stocks of Liquid Petroleum in United States*
Millions of Barrels

Year	Crude[a]	Increase over Preceding Year, Per Cent.	Refined	Increase over Preceding Year, Per Cent.	Total[a]	Increase over Preceding Year, Per Cent.
1926	309	R8.58	212	2.42	521	R4.40
1927	372	20.38	218	2.83	590	13.24
1928	385	3.49	229	5.05	614	4.07
1929	422	9.61	259	13.10	681	10.91

[a] Producers' stocks not included.

Table 2 shows the past trend and volume of crude oil in storage. California crude below 20° is excluded. It is significant that of the total increase during 1929, amounting to 37,000,000 bbl., 23,000,000 bbl. was in California light crude. The item of producers' stocks is omitted because it is not exactly comparable with past statistics. At the end of 1929 these stocks are estimated at approximately 7,000,000 barrels.

TABLE 2.—*Crude Oil Stocks*
Millions of Barrels

Year	California[a] 20° and Above	Increase over Preceding Year, Per Cent.	Mid-Continent Pipe Line and Tank Farm	Increase over Preceding Year, Per Cent.	Total U. S.[a] Except California Below 20°	Increase over Preceding Year, Per Cent.
1926	31	R29.54	174	R11.22	309	R8.58
1927	20	R35.48	247	41.95	372	20.38
1928	17	R15.00	266	7.69	385	3.49
1929	40	135.29	274	3.01	422	9.61

[a] Producers' stocks not included.

Table 3 is a compilation showing gasoline, gas and fuel oil and total refinery stocks, but not crude at refineries. Here again is evidence of lack of control on the Pacific Coast. Of the total increase in gasoline stocks during the year 58 per cent. was in California.

TABLE 3.—*Refinery Stocks, Total United States*
Millions of Barrels

Year	Gasoline	Increase over Preceding Year, Per Cent.	Gas and Fuel Oil[a]	Increase over Preceding Year, Per Cent.	Total Refinery Stocks[a]	Increase over Preceding Year, Per Cent.
1926	40	R0.33	112	5.33	212	2.42
1927	33	R16.23	126	12.06	218	2.83
1928	34	1.79	134	6.48	229	5.05
1929	44	29.41	146	8.96	259	13.10

[a] Includes California crude oil below 20°.

Fig. 1 shows the supply and demand for all oil.

Table 4 covers the statistics of supply and demand for petroleum. The 1929 figures are exceedingly misleading, because they give no effect to the shut-in production.

Imports of crude petroleum during 1929 were about equal to those of the preceding year, but imports of products, principally gasoline, increased about 20 per cent.

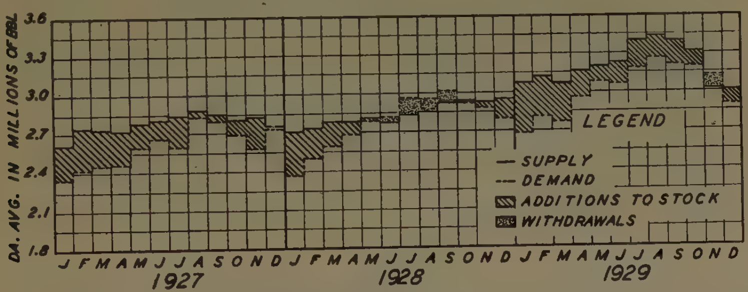

FIG. 1.—TOTAL UNITED STATES SUPPLY AND DEMAND OF ALL OILS. (IMPORTS AND EXPORTS REFLECTED.)

TABLE 4.—*United States Supply of All Oils*

Thousands of Barrels

Year	U. S. Crude Production	U. S. Imports (All Products)	Production Other than Motor Fuel	Total New Supply
1926	770,874	81,320	28,164	886,611
1927	901,129	71,736	34,417	1,014,084
1928	901,474	91,557	45,135	1,038,166
1929	1,005,598	108,619	55,326	1,169,633

United States Disposition of All Oils[a]

Thousands of Barrels

Year	Domestic Demand	Exports	Total Demand	Increase in Stocks
1926	778,842	131,494	910,336	R23,725
1927	804,578	141,035	945,613	68,471
1928	859,463	154,449	1,013,912	24,254
1929	940,214	162,257	1,102,471	67,162

[a] Producers' stocks not considered.

Fig. 2 shows published statistics of supply and demand of crude oil. The unsatisfactory conditions are illustrated at a minimum, as the shut-in supply is not reflected.

Fig. 3 reflects the high rate of development which continued throughout 1929 despite the increasing trend in shut-in and potential production.

Table 5 presents statistics of gasoline supply and demand. Included in these figures is the item of natural-gas gasoline and benzol.

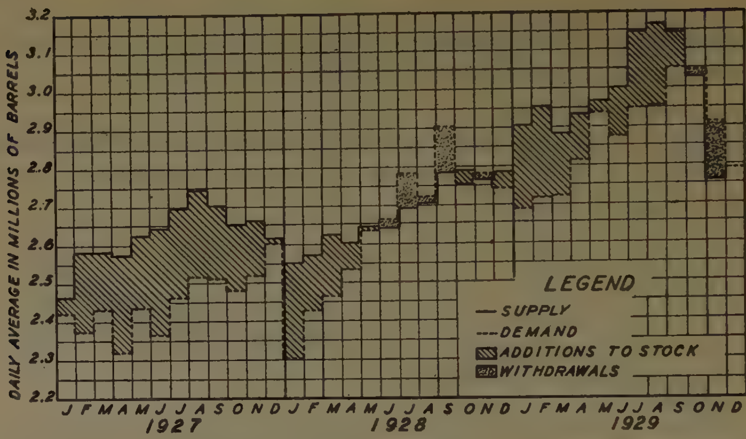

FIG. 2.—TOTAL UNITED STATES CRUDE OIL SUPPLY AND DEMAND. (IMPORTS AND EXPORTS REFLECTED.)

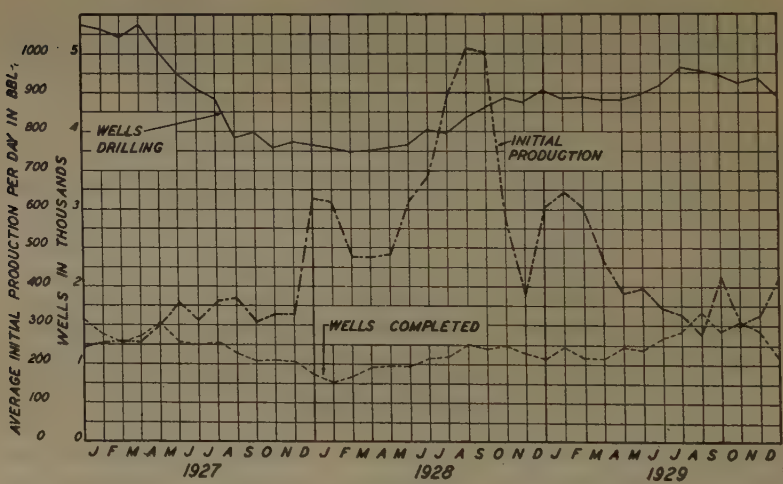

FIG. 3.—UNITED STATES WELL DATA.

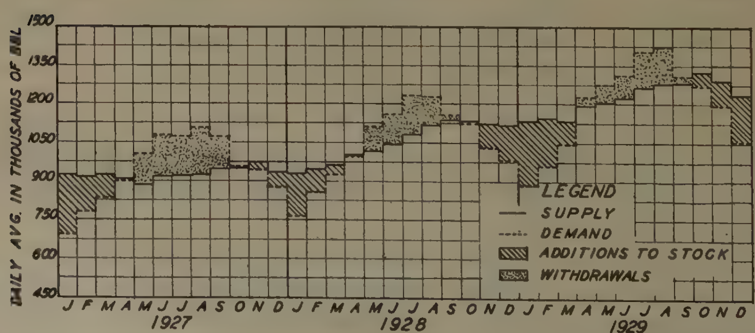

FIG. 4.—GASOLINE SUPPLY AND DEMAND. (IMPORTS AND EXPORTS REFLECTED.)

TABLE 5.—*United States Gasoline Supply*
Thousands of Barrels

Year	Domestic Production	Imports	Total Supply	Increase over Preceding Year, Per Cent.
1926	302,759	5,540	308,299	13.58
1927	334,281	5,002	339,283	10.05
1928	380,991	4,198	385,189	13.53
1929	438,551	8,868	447,419	16.16

United States Gasoline Demand
Thousands of Barrels

Year	Domestic Demand	Exports	Total Demand	Increase over Preceding Year, Per Cent.
1926	265,118	43,313	308,431	17.30
1927	301,362	44,337	345,699	12.08
1928	331,691	52,904	384,595	11.16
1929	376,175	61,208	437,383	13.73

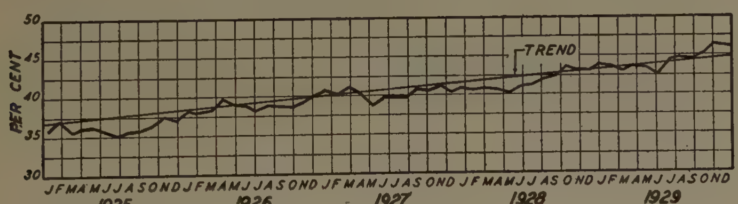

FIG. 5.—MOTOR FUEL PRODUCED (PER CENT.) PER BARREL OF CRUDE RUN TO STILLS.

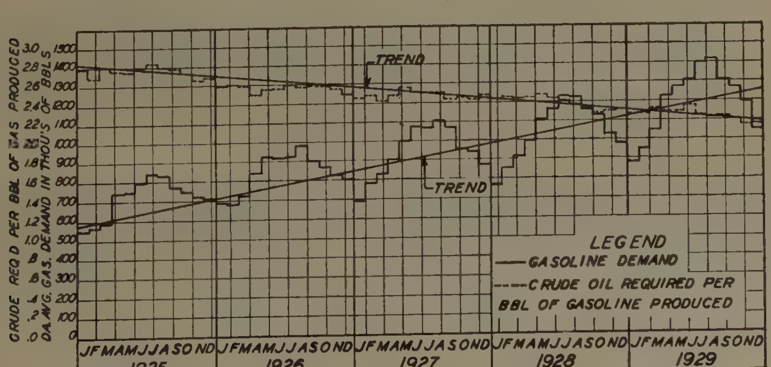

FIG. 6.—GASOLINE DEMAND AND CRUDE OIL REQUIRED PER BARREL.

Fig. 4 indicates how gasoline was manufactured without consideration of outlet. Fig. 5 indicates the trend of increased recovery of gasoline

based on crude oil run to stills. Entering into this compilation is the effect of cracking and production of natural-gas gasoline and benzol. Fig. 6 shows the relationship between increasing demand for motor fuel

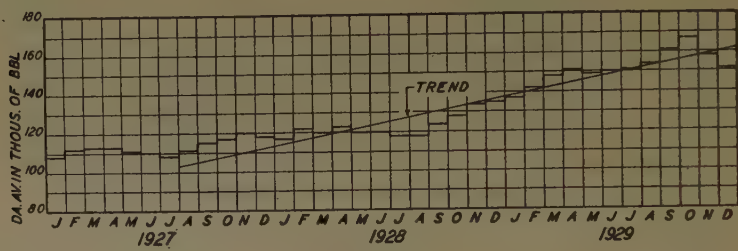

FIG. 7.—UNITED STATES PRODUCTION OF OTHER MOTOR FUEL.

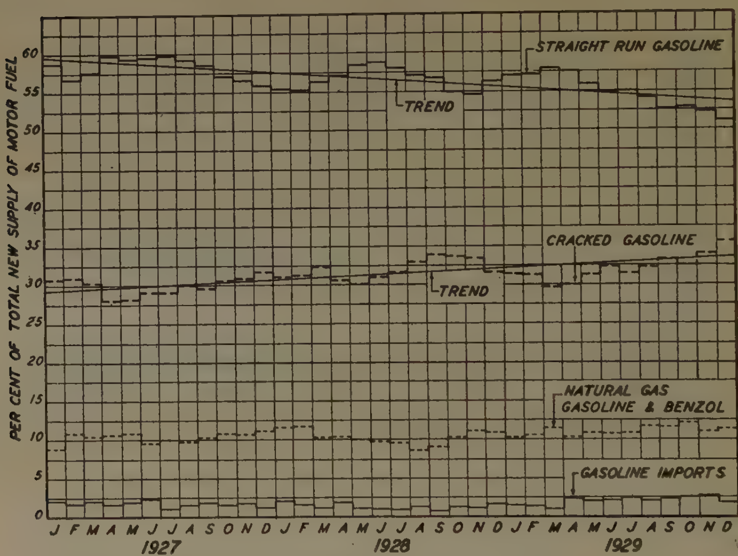

FIG. 8.—SOURCE OF UNITED STATES MOTOR FUEL SUPPLY.

and decreased unit demand for crude oil to meet it. Fig. 7 shows the trend of production of natural-gas gasoline and benzol. Fig. 8 shows in percentages the source and method of producing the United States motor-fuel supply.

Chapter XII. Petroleum Economics

Economic Trend of the Petroleum Situation

By Joseph E. Pogue,* New York, N. Y.

(Tulsa Meeting, October, 1929)

New economic forces are at work in the petroleum industry. In order to visualize these forces and to see clearly their bearing upon the producer, refiner, and marketer, it is necessary, first, to go back and gain a perspective of the economic evolution of the business.

Early Trend to Integration

For several decades prior to 1911, the outstanding feature of the petroleum industry was a trend toward integration, culminating in a huge combine, the Standard Oil Co. An important aspect of this integrative trend, however, was its concentration upon a combination and control of refining and marketing, leaving crude oil production, for the most part, to the exigencies of small-unit competition. It is a noteworthy coincidence that during this era the law of oil and gas was formulated and applied, whereby these substances had to be reduced to possession to establish ownership; and the forces of competition in crude oil production were thereby intensified. It was to the interest of an industry, safeguarded in its control of manufacturing and markets, to have supply stimulated by legal convention as well as by individual initiative in order that the growing demand could be met without interruption. And so overproduction of crude oil during this era was no handicap, but rather an aid, to the progress of the industry.

Disintegration

But the idea of superintegration, despite its efficiencies, became repugnant to the temper of the times and so the Standard Oil Co. was dissolved by Court decree—disintegrated into over 30 parts. And thus, in 1911, was ushered in the second era of the petroleum industry, a period of intense competition. This era coincided with the development of automotive transportation, and a tremendous growth resulted in the effort to keep pace with the mounting demand for gasoline. An intense individualism and unbridled competition were appropriate to this period of entry

* Consulting Engineer.

into the gasoline age; the wastes incidental to it were lost in the rigor of the growth.

During this second period, again, the feudal law of oil and gas was not unfit, or at least did not run seriously counter to the needs of the situation. For a time, indeed, it appeared that the supply of oil might fall short and so a "shortage idea" was born, which brought the larger companies hurrying into the field of production. This change was most important, for while it did not materially decrease competition, it resulted, first, in a differentiation of the field into two components, the independent producer and the producer affiliated with refining; and, second, it brought about a tremendous expansion in the technology of oil-finding and oil production.

Return to Integration

As a result, then, of an old law, inherited from the past; of the desire of large companies to assure themselves of an owned reserve of crude oil; and of revolutionary advances in technique, the supply of crude oil gained such impetus that new economic forces have been generated which are now carrying the petroleum industry into its third stage, marked by a return toward integration and control, as opposed to disorganized competition. It has become apparent, in short, that supply left to competitive forces alone results in chronic overproduction and, therefore, the manner of conducting the business must necessarily undergo a change to eliminate this flaw from an activity otherwise sound in its attainments and prospects. It is precisely the remedy of this defect that constitutes the major problem before the industry today, and it is fairly clear along what lines the solution will be found.

Anticipated Changes in Petroleum Industry

If present economic trends continue to their logical conclusion, the following changes in the petroleum industry will be witnessed:

The fundamental law of oil and gas, now at variance with economic needs and sound engineering practice, will be changed or modified; and oil pools will be operated as units.

Pending this change, the competitive pools will be more quickly depleted than the noncompetitive, or unit pools, leaving the latter segregated more and more in the hands of the larger companies (*i. e.*, producers affiliated with refining). This process will tend to lessen the role of the so-called independent producer. When this is appreciated, the independent producer, as a defense against his elimination from the oil business, will change his present opportunistic policy and work for a revision in the basic law of oil and gas, and also bend his efforts toward the furtherance of unitization and cooperation, developments really more essential to him than to the integrated company.

Physical integration will proceed to much further lengths than it has thus far attained, and the result will be the concentration of the industry into fewer and larger units, competing in the lowering of costs and the improvement of products and service, but cooperating in the control of supply.

Rationalization in the petroleum industry will be attained first in the refining and marketing branches, where this undertaking will meet less resistance and then proceed more slowly to the field of crude oil production, where more serious delays will intervene because of the inertia of obsolete legal restrictions and the ill-advised opposition of small interests.

While progress in the directions indicated will doubtless be slow, the logic of the situation is such that the forces of reaction will not prevail indefinitely and the forces of progress will in time gain the ascendancy. The very seriousness of the petroleum situation today, as it rounds out a decade of almost unbroken overproduction, is perhaps the best guarantee of the ultimate correction of the flaw that prevents this great activity from assuming its rightful place among the orderly conducted industries.

DISCUSSION

C. B. Mapes,* Tulsa, Okla.—It has been my thought for some time that other industries enjoyed a peculiar status, inasmuch as they seemed automatically to hold their production down to demand. Notable is the steel industry, which produces to meet demand. Does Dr. Pogue think it is possible for the oil industry to do likewise, and does the present trend indicate we will in time produce the oil to meet the demand and not just produce it at free will?

J. E. Pogue.—I do not know what is going to happen, but if present trends continue, yes. But to achieve this objective will require the development of an efficient type of collective management in the industry.

J. B. Umpleby,† Oklahoma City, Okla.—As an engineer I am willing to assume that if unit operation is sound engineering, sound economically, true conservation and to the best interests of all, existing law will be interpreted or modified to make it possible. It seems to me that the engineer's part in the problem is to contribute his utmost to the balance sheet of advantages and disadvantages. Not trained as a lawyer I fail to see how the unitization of individual pools can be considered in restraint of trade when we recall the great number of pools that contribute to the country's production.

H. C. George,‡ Norman, Okla.—I agree with the view that the oil pool must be operated as a unit. So far as the large companies go, no doubt that can be accomplished, which leaves the solution of the problem to the changing of the laws so that a pool can be operated as a unit, and that, of course, means the cooperation of all the fee owners and the royalty owners with the oil companies.

[For discussion of this paper by W. S. Farish see page 101.]

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† Geologist and Petroleum Engineer.

‡ Director, School of Petroleum Engineering, University of Oklahoma.

Controlled Gasoline Supply—the Key to Oil Prosperity

By H. J. Struth,* Houston, Texas

(New York Meeting, February, 1930)

A glance into the immediate future of the refining industry, and a retrospective view of 1929, cannot fail to emphasize the need for effective measures of control of refinery still runs. With oil producers alert to the need for control of the crude supply, it has become more than ever necessary for refiners to complete the movement toward stabilization by concerted determination to maintain still run schedules within the limitations prescribed by the demand for gasoline. The outlook for continued growth in the demand for gasoline appears to be well sustained by a preliminary survey of requirements for 1930. In fact, it is apparent that the industry will be assured of a market for gasoline that will aggregate in volume at least 472,000,000 bbl. this year. This indicates a gain in total demand over 1929 of about 9 per cent. or about 4.6 per cent. less than the gain recorded during 1929 over 1928, which amounted to 13.6 per cent. Despite the indicated increase in gasoline demand this year, it is apparent that little, if any, more crude will be required than last year. This is shown in Table 1, presenting estimates of gasoline demand and probable crude requirements for 1930.

Table 1.—*Preliminary Survey of* 1930 *Gasoline and Crude Run Requirements*

	Millions of Barrels
Domestic gasoline demand	397
Foreign gasoline demand	75
Total indicated demand	472
Natural gasoline content	53
Net gasoline from crude	419
Imported gasoline	13
Net gasoline required from refineries	406
Indicated excess stock Dec. 31, 1929	10
Maximum production required	396[a]

[a] At 40 per cent. gasoline recovery, this represents a maximum crude conversion of 990,000,000 bbl., or a daily average for the year 2,712,000 barrels.

Year after year, the refining branch of the petroleum industry has been found guilty of running crude to stills greatly in excess of normal requirements, causing frequent periods of market depression. A review

* Petroleum Economist, The Gulf Publishing Co.

of the situation during the past year not only discloses serious overproduction but also unnecessary additions to refined oil storage, which were the direct cause of declining prices, at a time when the market was in a position to respond to a favorable statistical position. The folly of continuing to run excessive quantities of crude through refinery stills is perhaps best illustrated by the fact that such action last year cost the industry, roughly, $105,000,000, representing the difference between the actual value received from the sale of motor gasoline in the domestic market and the value that might have been attained on the basis of prices obtaining during the preceding year. This is shown graphically

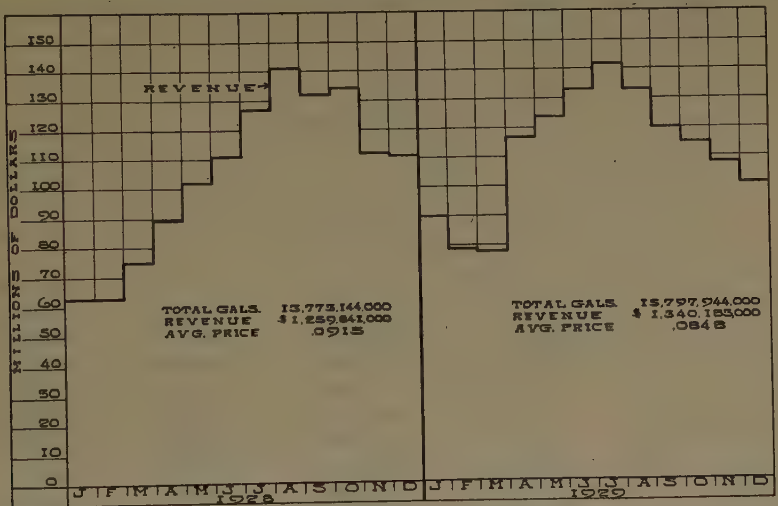

FIG. 1.—WHOLESALE REVENUE FROM DOMESTIC GASOLINE CONSUMPTION 1928–1929. Based upon composite price of 58–60° gasoline at refineries in Pennsylvania, Oklahoma, Kansas and California.

in Fig. 1, presenting a curve of wholesale value of motor gasoline for the three leading marketing groups over a 2-year period. The figures on the chart show that although the total revenue increased as a result of a larger volume, the average price was $0.0067 less during 1929 than during 1928. In view of the unusually large demand for gasoline last year, it is apparent that even slight effort to control the volume of crude processed at refineries would have resulted in a comparatively more favorable financial result, at least comparable with results obtained during 1928. The fact remains, however, that if it had not been for the unprecedented demand, the industry would have entered this year in far worse condition. As it is, the statistical position at present is far from satisfactory.

Dead Line Suggested

The fact that wholesale prices began to slump in the midst of the season of peak gasoline demand offers sufficient reason for the industry to

inaugurate a concerted drive against producing more gasoline this year than is indicated to represent normal market requirements. One sure way to accomplish this is for the refining industry to establish a "dead line" of still runs for the United States, based upon indicated demand, imports and actual excess storage of gasoline. A carefully prepared schedule of normal crude runs for 1930 is presented in Table 2 and is offered as a suggestion to the industry, as a basis for nation-wide curtailment.

In suggesting such an ideal for the industry it is, of course, realized that the degree of successful attainment depends not only on concerted action by the refining industry but also on the reasonable limits sanctioned by national and state laws.

TABLE 2.—*Refinery Crude Runs*
Thousands of Barrels

	Actual, 1929		Suggested "Dead Line," 1930	
	Total	Cumulative	Total	Cumulative
January	78,825	78,825	78,702	78,702
February	72,031	150,856	71,918	150,620
March	80,708	231,564	80,333	230,953
April	80,459	312,023	80,582	311,535
May	84,420	396,443	84,268	395,803
June	84,400	480,843	84,289	480,092
July	85,919	566,762	85,673	565,765
August	86,733	653,495	88,252	654,017
September	84,099	737,594	86,707	740,724
October	88,390	825,984	85,746	826,470
November	81,061	907,045	82,595	909,065
December	80,663	987,708	80,935	990,000
Total	987,708		990,000	

Having established a dead line for the industry in the United States as a whole, it is then possible to break down the sum total on a monthly basis to include each major refining group, which can, in turn, be prorated to smaller groups in the various refining states, and even down to individual plants, if necessary. Assuming that the suggested rate of monthly crude runs to stills will adequately supply this year's gasoline requirements, as well as take care of the indicated surplus accumulated last year, it is logical to assume that the adoption of this method of curtailment would readily lead the industry to a fair degree of stabilization this year. In fact, the author believes that the majority of those who give study to the conditions outlined will agree that unless some dead line is established this year, gasoline will command even lower values this summer than those obtaining last summer. Fig. 2 presents a graphic view of the

indicated normal course of refinery still runs this year, as well as the cumulative dead line, beyond which the refining industry cannot afford to process crude without inviting further demoralization of the structure

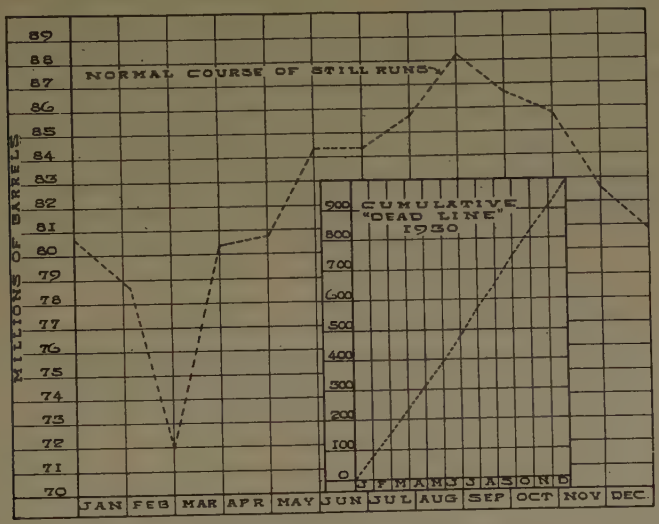

FIG. 2.—ESTIMATED NORMAL COURSE OF REFINERY STILL RUNS FOR 1930, WITH CUMULATIVE "DEAD LINE."

Curve represents maximum quantity of crude oil to be processed in order to equalize supply and demand for gasoline.

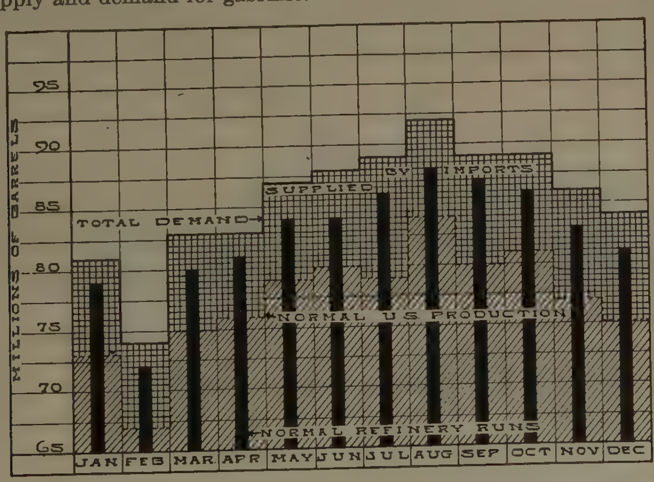

FIG. 3.—THE OIL INDUSTRY'S GUIDE TO NORMALCY FOR 1930.

Shows anticipated crude oil requirements, refinery runs and maximum crude oil production required from American producers.

of the refined oil market. This is amplified in Fig. 3, showing what the writer has designated as the petroleum industry's guide to normalcy for

1930. Since the industry will undoubtedly continue to import crude from South America, this chart contemplates the probable utilization of foreign crude oil by refineries, the net crude production figure for the United States resolving itself to the maximum quantity required to maintain at least a temporary state of normalcy. Thus, it is apparent that a complete picture of the gasoline situation necessarily includes a composite view of the crude production situation as well. In other words, complete stabilization of the petroleum industry involves serious consideration on the part of both refiners and producers, for when one branch is out of balance, the other suffers in direct proportion to the economic influence of either or both upon the market structure.

Refining Capacity Increasing

One important influencing factor in the overproduction of gasoline has been the constantly increasing rate of refining capacity in the United

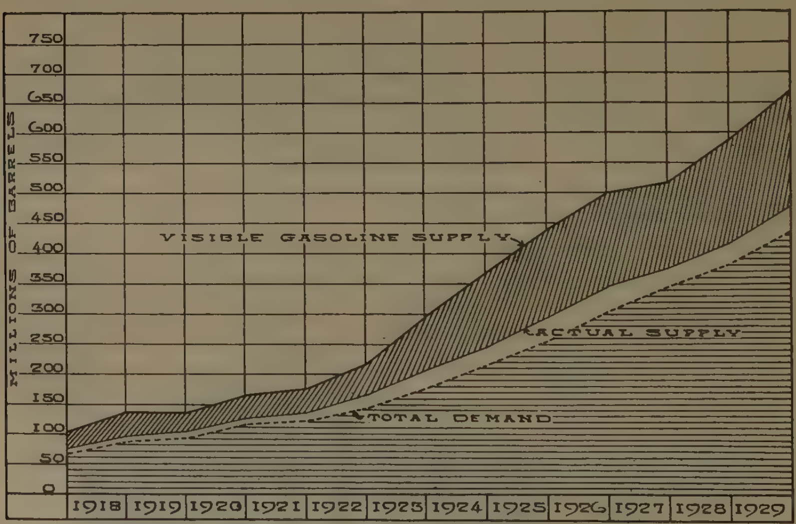

Fig. 4.—Trend of potential and actual gasoline supply, compared with total demand.

Visible supply restricts recoverable gasoline in crude stocks on basis of increasing recovery at refineries.

States. Each year finds numerous new plants in operation, while the installation of cracking facilities continues to increase the yield of gasoline and proportionately lower the rate of increase in crude demand. A record of the past 5 years reveals that the total refining capacity in the United States has increased at the rate of about 200,000 bbl., on a daily basis, each year, whereas, during the past 2 years, cracking unit installations have ranged nearly twice as large as that figure. In this connection

it is interesting to note that refinery cracking capacity in the United States is now estimated to aggregate about 1,772,000 bbl. daily. More than 200 refineries are now operating cracking units in the United States. Some idea of what effect this has had upon the potential gasoline supply can be obtained from Fig. 4, which shows the trend of visible gasoline supply in crude stocks, as well as the actual supply available each year. The widening area between actual and potential gasoline supply reflects to a marked degree the constantly increasing recovery of gasoline from crude. In comparison with total demand, this shows the situation that confronts the industry and makes it more and more necessary to effect some reasonable degree of control. Table 3 presents in detail the quantities of gasoline designated as potential and the actual supply as well as demand for each year since 1917.

Table 3.—*Gasoline Supply and Demand*
Million Barrels

	Potential Supply	Actual Supply	Demand
1917	104	76	66
1918	136	95	88
1919	136	102	91
1920	165	128	117
1921	176	135	121
1922	218	163	142
1923	297	206	177
1924	369	245	214
1925	440	294	255
1926	500	344	305
1927	519	374	342
1928	588	413	380
1929	667	476	433

Supply and Demand Ratios

The infallibility of the law of supply and demand as an influence on market price fluctuations of gasoline is exemplified best by a study of supply and demand ratios. This is clearly illustrated in Figs. 5 and 6, which show the trend of wholesale gasoline prices during the past two years in relation to the calculated index, which represents the supply-demand barometer. Fig. 5 shows the average prices prevailing each month at refineries in Oklahoma, Pennsylvania and California, in comparison with the supply-demand ratio for the United States. Fig. 6 presents a composite view of the wholesale gasoline market, as it applied to motor gasoline at the three leading refining groups, in comparison with the supply-demand ratio including the influence of crude. The barometer exerted a decided influence upon the course of gasoline prices

during both 1928 and 1929. Even more remarkable contrasts would be obtained by compiling separate barometers for each major refining district, in comparison with market prices obtaining therein. The point to be

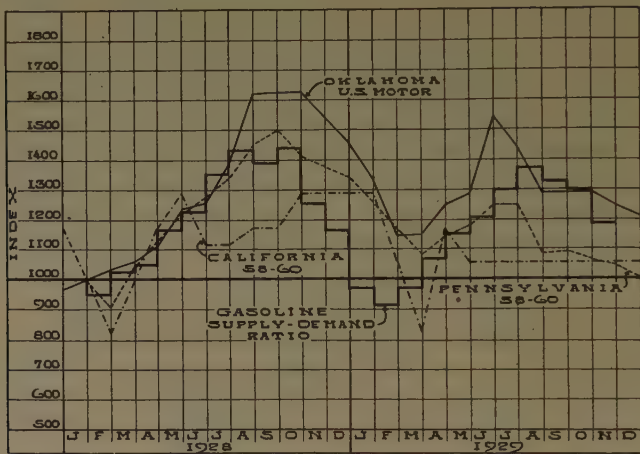

FIG. 5.—WHOLESALE GASOLINE MARKET PRICES IN RELATION TO INFLUENCE OF SUPPLY-DEMAND RATIO FOR THE UNITED STATES.
Note marked relationship between ratio curve and market fluctuations.

emphasized in this connection, however, is that a rising barometer invariably indicates a rising gasoline market, but as long as the supply continues to mount there can be little hope for better market prices.

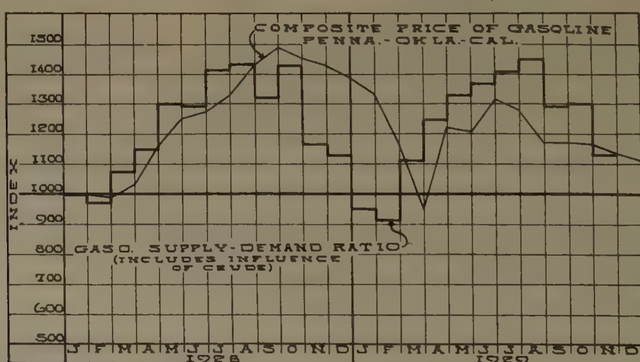

FIG. 6.—COMPOSITE PRICE OF 58°–60° GASOLINE IN OKLAHOMA, PENNSYLVANIA AND CALIFORNIA, COMPARED WITH SUPPLY-DEMAND RATIO OF GASOLINE, INCLUDING INFLUENCE OF CRUDE SUPPLY.

Everyone will agree that the range of prices that prevailed during the past summer were not in keeping with the real economic value of gasoline, but the cause of this is attributed almost entirely to the inability of the industry to maintain any degree of control over the supply. The

narrower price range prescribed by the composite curve in Fig. 6, in spite of the fact that the barometer indicated higher prices, is ascribed to the conditions that prevailed at refineries, as indicated in Fig. 5.

Another factor that aroused unusual comment during the past year was the influx of gasoline from the British West Indies and the increased shipments of California gasoline to the Atlantic seaboard. While it may be true that these sources of low-cost supply have forced refiners and marketers to cut prices in order to meet that competition, it appears somewhat ridiculous to assume that this comparatively small volume, which really represents less than 8 per cent. of the total American gasoline demand, could seriously affect the markets of a majority of gasoline manufacturers and marketers in the United States. This condition, therefore, simply emphasizes the apparent sacrifices that are made by the industry in the quest for more gallonage. It is possible that gasoline imports during 1930 will aggregate about 13,000,000 bbl. and California gasoline shipments to the Atlantic Coast may exceed 25,000,000 bbl.; a total of 38,000,000 bbl. On the basis of the indicated total demand this year, this quantity will represent about 8 per cent. of the total. The question before the industry is: "Will competition, representing only 8 per cent. of the gasoline business in the United States, dictate the market values of 92 per cent. of the supply?" On the other hand, California gasoline, while used in a competitive degree on the east coast, cannot be classed as outside competition, since California is as much a part of the American industry as any other section of the country. It is apparent, therefore, that the industry's foreign competition really represents less than 3 per cent. of the total volume marketed by the industry. In the face of expanding markets for gasoline abroad, it would seem rather absurd to insist upon an import duty on gasoline of 50 c. per barrel. The competitive angle of the gasoline situation seems to resolve itself to the conviction that the industry still has much to learn about modern merchandising of its products. It would seem as though a more direct and forceful method of solving competitive difficulties would be to pave new avenues to undeveloped markets, rather than demoralize the economic market structure of a product that commands a world-wide demand. Of primary consideration, however, is the urgent need for better control of the supply, the solution of which rests entirely with the refiner.

The phenomenal growth in the demand for American gasoline occupies a conspicuous niche in the annals of modern industry. Within a period of 13 years, the demand for gasoline has grown from a total of 62,000,000 bbl. in 1917 to a potential demand this year of 472,000,000 bbl. Yet, with all of this remarkable growth, the industry continues to complain of inadequate market prices. Overproduction is a term that applies most effectively to this march of events. Last year, and for a number

of years for that matter, the writer predicted the gasoline demand for 1929, and pointed out the limits of crude still runs prescribed by the indicated demand. The estimate contemplated a total demand of about 438,000,000 bbl., whereas the actual demand, as revealed by the U. S.

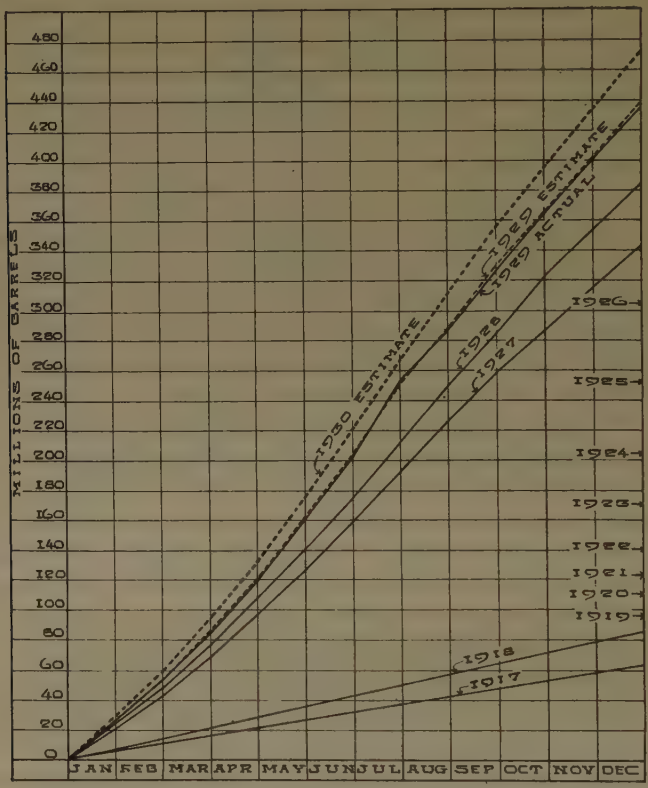

FIG. 7.—TREND OF CUMULATIVE GASOLINE DEMAND SINCE 1917.
Dotted lines represent estimates for 1929 and 1930. Note preciseness with which monthly cumulative gasoline demand was forecast for 1929.

Bureau of Mines reports, proved to be 433,000,000 bbl. The remarkable degree with which actual demand conformed to the monthly cumulative estimate is illustrated in Fig. 7, which also shows the actual trends of cumulative demand for each year since 1917, with culmination points indicated for the years 1919 and 1926. This furnishes an interesting picture, since the largest percentage gains apparently were made during the years following 1922 and preceding 1927. The year 1929, however, proved to be a period of unusually large consumption, exceeding the rate of increase established during the two preceding years. This also emphasizes the accuracy with which it has been possible to forecast the demand.

As indicated on the chart, the demand during 1930 apparently will not reach the rate of increase prescribed during 1929, primarily because motor vehicle registrations probably will not be in the same proportion as during last year.

In estimating the gasoline demand for 1930, due consideration was given to prospective sales of motor vehicles, as well as to the prospect of a further normal increase in demand from foreign sources. It is still too early to obtain figures for final motor vehicle registration for last year, but it is believed that the total as of Dec. 31, 1929, will exceed 27,000,000. It appears likely, therefore, even though the rate of sales falls below the rate established last year, that the registration figure will closely approximate 29,000,000 this year. On this basis, the average monthly registration during 1930 will be about 28,500,000, each vehicle consuming on an average of 506 gal. during the year. This reveals a total demand by motor vehicles in the United States of 14,154,000,000 gal., or about 337,000,000 bbl. In addition, there will probably be consumed a total of 60,000,000 bbl. for miscellaneous uses, and at least 75,000,000 bbl. for foreign consumption, aggregating in all about 472,000,000 bbl. Table 4 shows how the indicated demand during 1930 will probably be distributed throughout the 12 months. The last column carries a cumulative total, which has been plotted graphically in Fig. 7. The blank column, marked "actual," has been provided for the insertion of cumulative totals, domestic consumption plus exports, reported monthly by the U. S. Bureau of Mines.

TABLE 4.—*Gasoline Demands*, 1930

(Thousands of Barrels)

	Motor Vehicles	Miscellaneous Domestic Consumption	Exports	Total	Cumulative	
					Estimated	Actual
January	20,411	3,900	5,173	29,484	29,484	
February	20,766	3,709	4,622	29,097	58,581	
March	25,414	4,364	5,620	35,398	93,979	
April	26,374	4,855	6,725	37,954	131,933	
May	30,416	5,562	7,375	43,353	175,286	
June	31,477	5,755	7,723	44,955	220,241	
July	32,841	5,673	7,143	45,657	265,898	
August	33,094	5,945	6,434	45,473	311,371	
September	31,755	5,455	6,696	43,906	355,277	
October	28,850	5,127	5,593	39,570	394,847	
November	27,864	4,882	6,591	39,337	434,184	
December	27,738	4,773	5,305	37,816	472,000	
Total	337,000	60,000	75,000	472,000		

DISCUSSION

J. E. Pogue,* New York, N. Y.—In commenting on Mr. Struth's paper I wish to offer an explanation of the current overproduction of gasoline. As you know, the industry attempted last year to restrict the supply of crude oil, and in so doing, despite the addition of nearly 50,000,000 bbl. of crude oil to storage, the price of crude oil advanced and was maintained at a higher average level than the year before.

As a result of the type of proration control instituted, and of the higher price for crude oil, two consequences ensued. In the first place, producers owning refineries, made use of their refineries to give them an outlet for as much crude as possible. In the second place, the maintenance of an artificially high price level for crude oil, as a result of control, threw greater profits to cracking operations than to straight-run operations, and therefore stimulated the output of cracked gasoline and the construction of new crackers. Therefore, our current condition of gasoline overproduction is directly traceable to control of crude oil production, or, let me say, to the failure of the industry properly to control crude oil production so as to prevent the developments indicated.

Two years ago I commented on the factor of control in the petroleum industry, and pointed out that control was an important new economic force, but a dangerous one; that in most commodities where control had been tried, it broke down through faulty application or through improper use. In the petroleum industry control, as applied last year, has had an unfavorable bearing on the gasoline situation, and that I take it is not to be attributed to failure of control *per se*, but to the inadequacy of the type of control applied; and it also illustrates that it is a dangerous thing to go halfway with a new economic force and not to properly safeguard its application.

C. H. Osmond,† New York, N. Y.—The main point that I got out of Mr. Struth's paper and Mr. Pogue's remarks is that we are figuring on running too much crude to stills.

Mr. Pogue brought out the cracking situation. Cracking is an economic necessity, and there is reason back of installing economic equipment. It is sound, whether crude is high or low, because gasoline can be made with proper cracking equipment more cheaply even with low-priced crude than straight-run gasoline can be made. Another reason is the need for cracked gasoline to meet the type of motor fuel that is in demand today. Straight-run gasoline from the Mid-Continent or the Appalachian districts is not satisfactory; either cracked or ethyl must be added to it.

The important point to my mind, which we have not touched on—Mr. Struth discusses it in his paper—is the amount of capital invested in marketing facilities. We have invested so much capital there that the management demands gallonage. They must do something to show the reason for that capital investment, and that is the thing that forces this eternal fight for gallonage regardless of price.

An estimate today of our loss—and by loss I mean economic loss, because no one gains by it and many people pay for it—is 50 c. per bbl. on about 2,600,000 bbl. a day. The public is not any better off for the few cents a gallon less they pay for the gasoline; the industry is worse off. The industry is now receiving about $1,300,000 less a day from the public for its products.

F. J. Fohs,‡ New York, N. Y.—To what extent will the proposed building of gasoline pipe lines, or the proposed conversion of present pipe lines to gasoline carriage, cut the cost of delivering gasoline? Are there any figures available?

* Consulting Engineer.

† Consulting Petroleum Engineer.

‡ Consulting Oil Geologist.

C. H. Osmond.—There was a published tariff put out by the Standard Oil Co. of New Jersey on the transportation of gasoline. According to the rough figures it looked as if it cut the cost of transporting gasoline from the seaboard to the Appalachian Mountain district to about one-third of the cost by rail.

F. J. Fohs.—Then there will be other lines, I understand, to the Chicago district?

W. A. Sinsheimer,* New York, N. Y.—I have read of one gasoline line being proposed to that district. Has anybody here any information on those costs?

E. R. Lilley,† New York, N. Y.—I have no definite information on the costs. I think the estimate of one-third is somewhat low. It seemed to me that it was about 40 to 50 per cent.

There is one point I would like to bring out in answer to Mr. Fohs' question. The line that is being used by the Standard is an oil pipe line, the value of which, or the cost of which, has already been well paid for. The whole investment has been amortized and it has only junk value. The cost, then, becomes a factor that cannot be used in a discussion of the possibilities of constructing a pipe line such as is proposed to connect the refineries in the Mid-Continent with Milwaukee. There the situation is entirely different.

W. A. Sinsheimer.—The junk value of that line might be questionable. Of course, what has made it a junk line is the fact that crude now is moving principally to the Gulf Coast and then around to the Atlantic seaboard by water, but I also understand that ocean tanker rates have been soaring in recent months, and it might be that the use of all-pipe routing through the Mid-Continent to the Atlantic seaboard might come in again.

E. R. Lilley.—If that is the case, certain of the companies that have recently sold pipe lines to the gas companies are going to feel very sad indeed.

W. A. Sinsheimer.—I do not say that it will be the case, but there is that value in old crude lines.

E. R. Lilley.—I can not conceive of it.

F. J. Fohs.—In his estimate of refining facilities, has Mr. Struth included the new plants, such as the Pan American, built and being built in Venezuela or off the Venezuelan coast?

H. J. Struth.—No, I have not.

F. J. Fohs.—To what extent will their refining facilities be completed this year?

H. J. Struth.—I am not prepared to answer that question.

F. J. Fohs.—I think, in considering this problem, you have to take into consideration what imports there would be from such sources, because they will be material. I am not sure whether the Gulf Refining Co. has a refinery there also. If not, they are importing part of that crude to Port Arthur and refining it.

H. J. Struth.—As I understand it, the Shell company seems to be the biggest exporter of gasoline from the Venezuelan coast.

F. J. Fohs.—Another point that seems to me has to be taken into consideration in this subject is talking principally about profits from gasoline and from crude.

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† Associate Professor of Geology, New York University.

There are other refined products outside of gasoline and fuel oil and for these there has been no cut in prices. In none of the discussions have these products been taken into consideration, and for the larger refiners the profits from these are material.

Another point that is important and bears on the whole problem seems to me to be the spread between the price at which the refiner sells and the price at which the retail marketer markets gasoline in this country. That spread is material. In some districts it is very great, California, for example. The price of fuel oil, I believe, has been rather high in some portions of this country.

All these factors ought to be considered.

As regards the general situation (of course I am primarily in the producing end of the business and aside from any bias I may have as a result) I believe any attempt to compose the oil situation without material reduction in crude runs to refineries and cracking plants, will not make any great change in the present situation.

E. R. Lilley.—Mr. Struth, in Fig. 4, you use the term, "visible gasoline supply." Will you tell me what that includes?

H. J. Struth.—That includes the total actual supply on hand, plus the quantity of gasoline that is contained in crude stocks. In other words, it includes the potential gasoline in crude stocks. If we took all the crude on hand and refined it, we would have that much additional.

J. E. Pogue.—It does not include the gasoline in the crude potential?

H. J. Struth.—No, just the actual crude stocks.

E. R. Lilley.—I had interpreted it to be refining capacity, and thought that you meant it to indicate the quantity of crude that could be run through the refineries, of the quantity of gasoline that could be produced in them.

H. J. Struth.—No, it merely shows the potential supply of gasoline available.

E. R. Lilley.—I want to go back into ancient history, to that period in the oil business when control was most complete, that is, when the Standard organization was practically the only large refiner in the business. If there is anything to be secured through control, certainly it should have been secured than. Let me read these figures. They are figures that were presented in the investigation of the Standard Oil Trust in 1907 and 1908. The prices are in cents per gallon.

Period	Average Price of Crude Oil in Pennsylvania	Average Price of Kerosene in New York	Margin between Crude and Kerosene Prices
1863–1872	10.5	37.6	27.1
1873–1882	3.1	12.3	9.2
1883–1892	1.9	7.4	5.5
1893–1902	3.0	6.8	3.8

The price of gasoline is following a similar curve, and will continue to do so. In the past, the margin between the price of crude oil and the price of gasoline has been very high. We are going to have lower prices for gasoline in the future, even if the price of crude oil rises somewhat above its present levels. Of course, whether the price of crude will rise or not, is an open question. However, we should remember that even with low prices for gasoline and for crude oil, some profits will be made. For

some individuals there will be losses; for others, just enough to balance expenses; for some, substantial profits. The class to which any individual belongs depends upon the strength of his organization, and to luck to a certain extent.

If we start with the period immediately after the War, we find that we had a gasoline market far greater than our refining facilities. We had high prices and, in consequence, a large margin to work on. The industry kept that margin for a while, and then began to cut into it. First, it improved its transportation facilities and then its refining facilities, and, finally, it began to develop cracking equipment on an unprecedented scale. As we use more cracking equipment we produce more gasoline per barrel, and can afford to reduce that margin between the cost of crude oil and the price of gasoline.

How long is it going to take before that margin becomes stabilized? I have heard a great deal about the overproduction of crude oil. I have heard much about the profits of refiners. I think it would be fair to say that refiners have a substantial control over the extent of their operations during the past few years, have maintained crude prices at levels that were too high. In part, I believe this to be due to the desire to assure themselves of a steady supply of crude oil for their profitable refining operations. The consequence was that the crude producer, although securing a fair price for his product, felt that he was not receiving his full quota of the profits of the oil business. To secure this, he went into the refining business.

Let us look over the list of Mid-Continent and California companies that were primarily producers, six or seven years ago. They are practically all in the refining business today. They must have outlets. Why did they go into the refining business? The answer is evident. The margin between crude and refined was great. It looked like a profitable business. Now, that margin has shrunk. Does it not appear that the refiner has done as much toward bringing on overproduction as the producer?

We have heard that cracking is economically desirable as a means of conserving oil resources, and as a citizen of the nation I am interested in conservation. As a stockholder of an oil company, I am not. Conservation which means attempting to use crude oil for purposes that it can be used for successfully 50 years hence, may be poor business. The price of crude oil and the price of gasoline and the price of fuel oil are all factors that are going to determine whether we crack or not. If the margin between crude oil and fuel oil is very slight, cracking facilities are undesirable. We have probably not quite reached the point where we have excessive cracking facilities, but unless the price of gasoline goes down, or unless the margin between fuel oil and gasoline is decreased, we are going to have more cracking facilities than we need, and ncoe they are built they represent such an enormous investment that they must be used.

M. G. Cheney,* Coleman, Texas.—Just another producer seeking a ray of hope. It seems one may become either cheerful or despondent over the statistics on oil and gasoline. If the supply and demand over the past 10 years, or more, are compared on a percentage or per-car basis instead of merely total figures, the present situation would seem to be highly favorable rather than alarmingly bad.

I believe I correctly recall data recently published which showed that the average car now uses about 600 gal. of gasoline annually instead of 450 gal. as of 11 years ago, and that in spite of this the reserve stocks of crude and gasoline are 20 per cent. less per car than 11 years ago, when crude oil was considered worth as much as $3.50 per barrel.

I wonder if there ever has been a time when there were not many inside locations on leases which could be produced and drilled. In other words, we have always had

* President, Anzac Oil Corpn.

large potential supplies in sight. The present stored reserves are larger than ever before but have they gained any faster than demand? I recall in Fig. 4 of Mr. Struth's paper that the potential supply in 1918, I believe, was 50,000,000 bbl., or something like that, and now it is something like 200,000,000 bbl. Yet at the same time, during this period, the demand has increased from about 50,000,000 bbl. a year to about 400,000,000 bbl. a year. Is this out of line? I do not see, if supply and demand are compared on a percentage basis, or a per-car basis, that it presents such a pessimistic situation now, particularly when only during the last 2 years has the industry seen the necessity and advantage of cooperating, and through state laws the way has been provided to regulate supply far more than ever before.

The price has been low. It was reduced further following the recent cut in crude, which was an arbitrary procedure not approved by the majority of oil executives. This development does not necessarily represent a free play of the law of supply and demand in so far as crude oil is concerned. Many economists attributed the low gasoline prices solely to an excess of refined products, due to continued bad weather and subnormal demand and lack of cooperation among refiners to reduce current runs accordingly. Hence the strong feeling among producers that these particular crude cuts were unjust.

Problems of Petroleum

By J. Elmer Thomas,* Fort Worth, Texas

(New York Meeting, February, 1930)

The evolution of the oil business is one of the great industrial romances of modern times. First used as a medicine, then as a lubricant, then as an illuminant, and finally as a motor fuel, each change in its principal usage caused large increases in consumption.

Producing Successes

The producing branch of the industry responded ably to the demands made upon it. Never was there a famine, rarely any threat of scarcity, and stored inventories were gradually accumulated to form comfortable working stocks. Originally an erratic and hazardous undertaking, the discovery and development of oil fields has made such strides as to classify now as a science.

When storage stocks were low, production in close balance with consumption, and demand trending sharply upward, considerable concern was expressed over future needs. Price was very responsive to fluctuations in supply under those conditions, and quotations for crude and refined oils exhibited wide swings. A very different situation exists today.

Consideration of the statistics only since the war will show how recent has been this change. In the 10-year period from 1918 to 1927 inclusive, we produced in the United States 6,100,000,000 bbl. of crude and imported 900,000,000 bbl., our total supply being 7,000,000,000 bbl. The consumption was 6,600,000,000 bbl., thus adding to stocks 400,000,000 bbl., an accumulation of somewhat less than 6 per cent. of the total supply.

During that period virtually every field was promptly developed as soon as discovered and nearly every well in the country was producing at full capacity. With the maximum production of the wells required to take care of the rapid increases in consumption, with storage stocks moderate and proven reserves very slight, the producing division of the industry acquired a tempo not needed now.

Potential Surplus

Today the situation is vastly different. The economic consumption is about 2,700,000 bbl., with current production slightly in excess of that.

* Petroleum Analyst, Fenner & Beane.

There is an additional potential production, however, from wells already drilled variously estimated at from 1,000,000 to 5,000,000 bbl. daily. Perhaps the mean between those figures would be closer to the facts, but the exact amount is unimportant.

The present potential surplus is mounting rapidly but it is much smaller than it would have been, were it not for the drastic curtailment in drilling operations during the past two years. Looking to the immediate future, there is every indication that many if not most of our remaining fields will be discovered with great rapidity. Further increases in our potential overproduction may be expected for some time to come.

Many years have been spent in learning how to find oil and many millions of dollars spent for oil leases on areas supposedly favorable for crude production. Now we find that we do not need so much oil so soon. But oil leases are in effect optional drilling contracts and expire within a few years. Incessant drilling operations are required to test them before expiration.

Irrespective of the immediate outlook for the industry, this prospecting will continue at a high rate of activity. No price reduction can be severe enough to prevent the exploration for new fields. When discovered, they will be developed to a sufficient extent to hold the leases. Low prices may prevent the operators from selling oil but it will not dissuade them from proving up their leases. For these reasons the industry obviously faces an extended period of still larger potential surplus production.

This has caused certain profound changes in the fundamental economics of petroleum, changes so recent that the entire industry is not yet fully aware of them, and changes so pronounced that various units interpret them in strikingly different ways. For physical and financial reasons, methods which were used advantageously in the recent past can no longer be applied and different economic practices must be employed.

Perhaps some theoretical economists would hold that prices now must be depressed until profits are eliminated and the excess supply worked off at bankrupt levels. Such a waste of an exhaustible, irreplaceable natural resource would be unthinkable. If the governmental authorities or the public at large were aware of it they would not permit that to occur.

Control and Conservation

Obviously the situation calls for control and some form of production control seems inevitable, regardless of the antagonism of some oil producers, the diffidence of some governmental authorities or the indifference of the public. Happily, control and conservation go hand in hand and thereby all parties concerned will be benefited, as is readily apparent.

The producer can hardly exist for long without it. This has been demonstrated most forcibly during the past few years when several

bonanza pools have been discovered at different times in different parts of the country, any one of which was sufficient to demoralize the producing branch if developed at the former frenzied rate and dumped onto an overburdened market. With operations conducted in an orderly, businesslike and restrained manner, such development should be highly profitable.

The interest of the government lies in the security of an adequate supply for national defense and in the proper utilization of a great natural resource. The interest of the public lies in obtaining its petroleum products in sufficient amount, over an extended period, and at prices neither lowered by wasteful production nor raised by extravagant costs.

This whole question of conservation should be approached wholly upon its merits and completely divorced from considerations of price. From the standpoint of the producer, a fair commodity price is possible only if production is in reasonable balance with consumption. From the standpoint of the consumer, he can enjoy a supply sufficient for his needs at a lower price only when unnecessary expenses are eliminated from producing, transporting, refining and marketing.

With this community of interests the government should be on the same side and should enforce conservation without the imposition of any price restrictions. In such a competitive industry experience has shown that the economies of producers are promptly passed on to consumers. In the long range view, for the latter to secure the vast supplies they require, it is necessary for some one to make a profit, and while lack of control would gradually break down weaker units it would not eliminate profits from those more fortunately situated.

The industry has made a magnificent effort towards self-control. It is treading new paths in strange territory, but its first attempts have been most commendable. There still remains the necessity of making this temporary and voluntary control permanent and secure. A better balance will be required as between various flush pools in the several producing states, but the industry has become conservation-minded and a start has been made. The draft upon crude stocks during November was no mean achievement.

Marketing

The problems of the producer are too closely involved with those of the marketer to consider either independently. Here again is a case of large over-production (gasoline), evidently more serious because apparently less controllable. The excessive manufacture of gasoline is largely due to the overproduction of crude, and a brief review of how it has come about will emphasize that relationship.

As various individuals or corporations developed production in important amounts, they became the nucleus for new refining organiza-

tions. Originally they may have entered the field to participate in the refining profit but more recently the impelling motive has been to ensure a market for crude supplies. For most of them the expansion was confined for many years to the manufacturing branch, products being sold on the wholesale market.

While an abundant supply of cheap raw materials is essential to the success of any manufacturing enterprise, the tendency toward crude overproduction in recent years, oddly enough, caused an unsatisfactory wholesale price for gasoline although retail quotations did much better. The next step was to buy, build or consolidate the refining units with bulk and service stations, completing the integration.

Surplus Filling Stations

In spite of the phenomenal increase in gasoline consumption, distributing facilities have been grossly overbuilt. In many cases these retail outlets have been expensive investments for the refiners but ownership or control by various contracts and understandings has progressed to the point where there is now virtually no open market available for wholesale gasoline.

Any unit desirous of expanding its business is therefore compelled to extend its own distributing facilities, thus aggravating this unfortunate condition.

It has been estimated that 85 per cent. of the gasoline sold in this country is marketed direct by the refiners through their owned or controlled retail outlets. This has almost destroyed the spot market for gasoline. Perhaps two-thirds of this refiner-distributed gasoline has been manufactured from crude produced by themselves. Thus the posted price of crude has become less important except for its waning influence on tank-wagon prices.

All of these recent developments have combined to force the duplication of marketing facilities to the point that a normal margin allows no retailing profit. The service stations of one fair-sized city are known to market less than an average of 75 gal. daily each. This is probably the most serious problem affecting the industry today and its solution may prove the most difficult.

The Trade-mark

Much of the blame for this expensive and inefficient system must be laid to the trade-mark fetish. There is perhaps less excuse for trademarking gasoline than almost any other commodity so widely used. Made by numerous companies with various methods from different crudes, the end product is fairly uniform. While there are minor differences the essential qualifications of motor fuels are prescribed and are universally adopted.

In the second place, no company has the facilities to supply the needs of a nation-wide public efficiently. Insofar as a company attempts to spread its sales effort over a wide territory it necessarily duplicates, in whole or in part, entirely adequate facilities of others already in existence. Excessive selling costs and unnecessary freight charges are the result and somebody has to pay the bills.

The adoption of standard national specifications and the elimination of trade-marks would permit dispensing with fully half of the present dealers. The resultant saving to the public and to the industry would be so great that it appears to warrant serious consideration. It may be doubted that these highly competitive companies will readily adopt such a program. Expensive investments for distributing properties and large appropriations for brand advertising have been made. And the mad race for gallonage goes merrily on.

Some better method of obtaining efficiency and economy in marketing, apart from this question of trade-marks, may be devised, but until it is developed the income department of the oil industry will not be in a satisfactory position. Control of crude production, now on the horizon, would remove the necessity for many of these facilities and consolidations may come then.

Controversies

While the industry and its fundamental economics are undergoing such profound changes, many differences of opinion are bound to arise. No group of freethinking people ever agreed upon any complicated question. Different units are controlled by different interpretations of the economic background and the recent sharp controversy over crude prices is an example of disagreements which are bound to occur. There is very little solidarity among such highly competitive companies.

The entire industry, however, is rapidly coming into complete accord on the two major problems discussed herein, the utter necessity for control of production and the unwarranted duplication of marketing facilities, largely caused by the trade-mark. The oil business and its able leaders have weathered many storms successfully. They may do so again, and soon.

Petroleum is an essential industry and its profits must be preserved.

DISCUSSION

J. B. Umpleby,* Oklahoma City, Okla.—The oil situation has ceased to be governed by supply and demand and its destiny for the near future at least has become a problem of production control. In other words, the human element has become a dominant factor during recent years. There are, however, certain important aspects of the situation in which human control has not much latitude. The picture is that

* Geologist and Petroleum Engineer.

of a great industry notorious for individualistic action, building up during the last few years in one field after another great excess potential production. I think of it as a great tidal wave piling up and the problem becomes: is it going to break or can it be held in check?

The lease situation is particularly difficult to control. In 1927 and 1928 in the Mid-Continent, we saw a rapid transition from 5 to 10-year leases, and at about that time, curtailment coming in because of overproduction in Seminole. Since then drilling has been postponed year after year wherever possible. Normally the old 5-year leases would have been extended, but coming into the picture along with Seminole was a most remarkable recognition of royalty as a speculative investment. Within 2 or 3 years the renewal of leases required several, rather than one signature. From 10 to 100 royalty owners under a desirable tract is not uncommon. Renewal of leases thus becomes not only much more difficult, but much more costly. What are the consequences? To be specific, I understand that in Kansas one of the companies spent $3,000,000 in core-drill and other special investigations. Based on these studies 5-year leases were taken on a large number of structures and these leases expire in 1930, 1931 and 1932; very few of them have been extended. Development to date has been encouraging. What are the companies owning those leases going to do? The only way they can possibly protect their investment is to drill, and it would seem quite unfair to censure them for doing so. This situation holds on a large amount of potential acreage in the Mid-Continent. It places the burden of a solution of overproduction on control after production is found, not on a drilling moratorium.

These facts must be taken into account; meanwhile the tidal wave piles up. The solution, as far as I can see it, requires artificial control, and that control necessitates continued cooperation throughout an industry that has been notorious or individualism.

E. R. Lilley,* New York, N. Y.—Last year I asked Mr. Thomas a question and he can still laugh at me. I suggested that the copper situation would eventually result in disaster. He is able to show a year of profits to me. I would like to ask him one more question, however.

Mr. Thomas, let us assume that you are in the gasoline business and that you have bought a plot of ground, and that the State Highway Commission changed the road. Let us say that you leased the ground, and the new State highway, because of this change, goes a mile away. The plot that you have leased is on a side road passed by three cows and ten pigs every day; and there is a plot of ground at a good corner on the new road. Would you give up the old lease and get a new lease?

J. E. Thomas.—Yes.

E. R. Lilley.—If you were out in Oklahoma and you were losing money, and you had a number of high-priced leases, would you drill the wells on those leases or would you sell those leases for what you could get and go elsewhere where there were cheaper leases and more oil available?

J. E. Thomas.—I will merely point out to Dr. Lilley the difference between the very small, very minor, very narrowing fluctuations in retail merchandising profits, and the whole limitless vista of prospecting. My well in Oklahoma may be a good well or a bad well, but I will certainly drill the well, as they do, and will, drill such wells.

E. R. Lilley.—The point that I wanted to bring out is this. When you hold a lease, a ten-year lease, say, for seven or eight years, without drilling, you certainly

* Associate Professor of Geology, New York University.

have not a great deal of faith in the oil being there or you would have drilled it earlier. Why not give it up?

J. E. THOMAS.—How are you going to get your money back? You spent millions of dollars on this lease.

E. R. LILLEY.—Not on this lease; this is only a small lease. Those companies who gave up such leases and went to California and procured cheaper leases have not been hit so badly.

J. M. LOVEJOY,* New York, N. Y.—I do not think Mr. Thomas' remarks about trade-marks were very well thought out; I do not see how the industry could possibly get away from the use of trade-marks. If the Texas Company is going to sell gasoline, it is going to sell Texaco gasoline, and it is not a practical proposition to do away with its trade-mark. Trade-marks cost money to maintain, I will agree with that.

The other statement that Mr. Thomas made, as I recall it, was that conservation should be considered entirely divorced from the question of price. I do not agree with him on that. If conservation that will either greatly raise or lower the price is to be put into effect, it would not be sound either way; therefore in considering the problem of conservation it must go hand in hand with price. You might not talk about it; they just supplement each other and it cannot be avoided.

Mr. Thomas is certainly more of an authority on oil stocks than I am. Every time I buy any they seem to go down. The position today appears to be that oil stocks, since the panic this fall, have not recovered, whereas the rest of the market has, so a continuation of the curves described by Mr. Bryan[1] would certainly show a divergence at this time. I think the second-grade stocks at least, such as Barnsdall—Pure Oil—Mid-Continent class of stocks—are just as low, or practically the same price now, as they were at the very lowest stages of the panic. The Standard Oil Co. of New Jersey, and some of the other larger ones have recovered a little, but no oil stock has recovered in proportion to the steels or utilities and some of the other standard stocks.

Again, I think we have today a peculiar situation in the second-grade companies—that they are selling today at a ridiculous value considering their assets. One company is selling around $18 per share, and has actual current assets of $15 per share, so that its rather wide production and all its properties, which are extensive, represent only $3 per share. The reason is that the dividend outlook is not good for that type of company. But on the basis of assets there are many companies that are selling ridiculously low. Any one of us can take a pencil and paper and figure assets probably twice what those companies are now being quoted at.

* President, Petroleum Bond & Share Corpn.

[1] B. Bryan: Influence of Control in the Oil Industry upon Investment Position of Oil Securities. See page 430.

Influence of Control in the Oil Industry upon Investment Position of Oil Securities

By Barnabas Bryan,* New York, N. Y.

(New York Meeting, February, 1930)

In the year 1875, the Pennsylvania Supreme Court, acting on incorrect information concerning the production of oil and gas, established what has become the law of the land for the governing of oil production. While the decision was ideal for the refining monopoly which was completed in that year, there is no evidence that the court was in any way influenced by that refining monopoly. The evidence indicates that the court accepted the view of the royalty owner and independent oil producer.

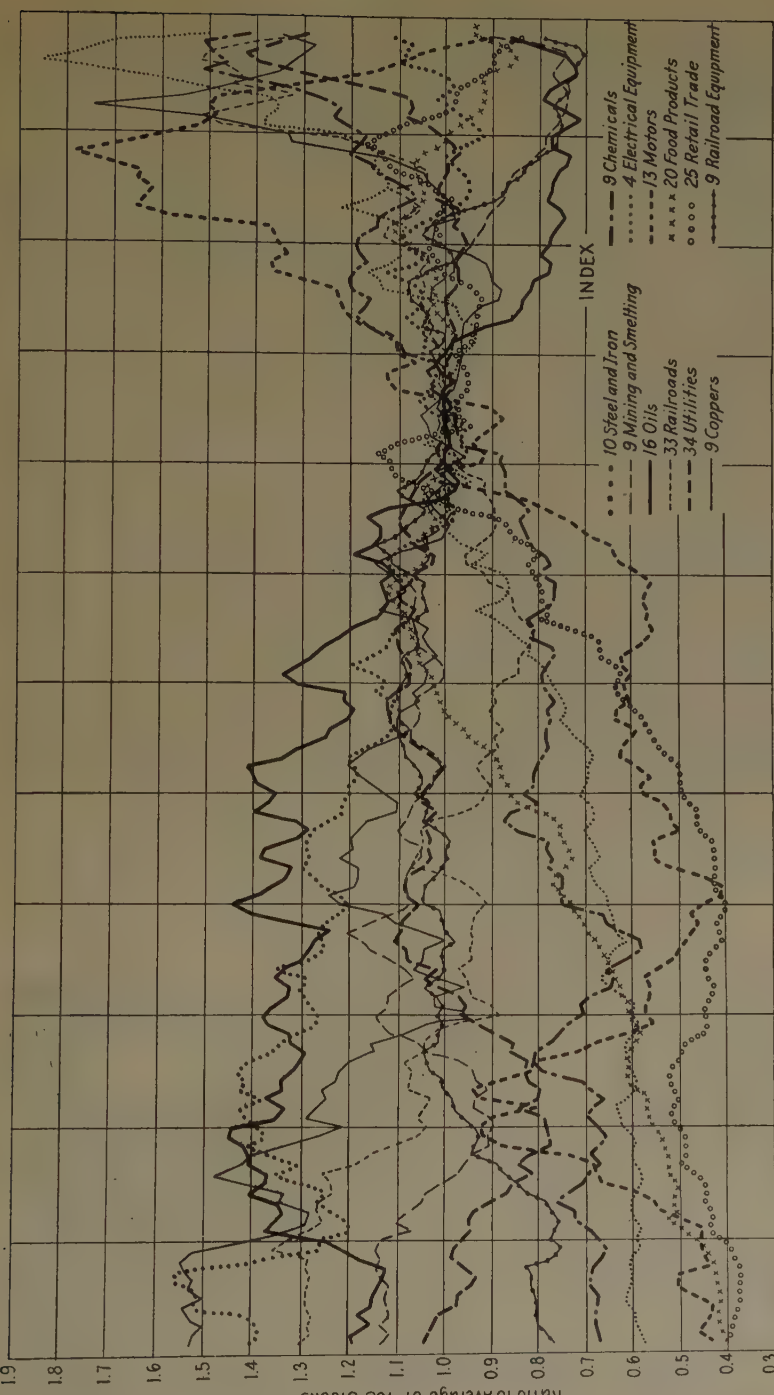
Throughout the life of the refining monopoly it accepted this law, which was so evidently to its advantage in securing cheap raw material. The same policy continued until the development of the exhaustion theory and the entry of the various units of the former monopoly into the production of crude oil. It is curious that no one doubted the new theory of shortage sufficiently to feel the need of changing the law. When the theory entered the economic field sufficiently to raise crude oil prices beyond justification it shortly disproved itself, but by this time the question of split ownership in producing fields made a change from legal error to justice too complicated to be undertaken by the large companies. Not even the ardent advocate of unit operation dared to carry the question to the United States Supreme Court, which has never been asked to pass on the complete question.

The impossible position of the producing industry, hemmed in on one side by court law compelling wasteful production and on the other by the national law against cooperation, lasted until the demoralization of 1927 led to cooperation within a state and under state guidance. Since that time control of production has grown with the bringing in of each new field and at this time has the active support of the Department of the Interior in such ways as are definitely legal. As in 1875, the royalty owner and independent producer are opposing by all possible means the rational conduct of the business of producing crude oil.

Fluctuation in Investments

The investor in oil securities has not been as badly fooled as has the oil man himself. Fig. 1 is designed to show the composite regard of all

* Pettigrew & Meyer, Inc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Ratio to Average of 405 Stocks

Fig. 1.

investors to the different industrial groups in the market. The various group curves are the Standard Statistics price indices by groups, divided by the price index of the 405 stocks of the complete index. Each curve therefore shows the strength of a group in relation to the general estimation of security values.

The oil curve shows conclusively that from the year 1920, when the exhaustion theory reached its greatest acceptance, until the fall of 1927 the investor continually lost faith in the oils, while since the fall of 1927 he has gained in appreciation of the possible future for the oil industry. From the fall of 1919 the highs and lows of the relation of the oils to the market show a declining trend. In other words, the oils were in a continual bear market from 1919 to 1927. Since the fall of 1927 the trend of the oils has changed, first to a flattening or constant relation to the market and later the beginning of a rising series of highs and lows about the market averages.

There can be no question of the cause for this change in the performance of the oil stocks, since its beginning in 1927 correlates exactly with the beginning of the correction of the most fundamental difficulty to be found in the history of oil—the inability to control its raw material in line with demand. This one fact has been the cause of irregular earnings by the good companies since oil was first produced. There has been a succession of periods of oil shortage followed by much longer periods when new discovery made oil a drug on the market and thus diminished earnings to the point of eliminating many company dividends. In none but the firmly intrenched large integrated companies could the investor depend on a continuous income from oil investments. The entire industry was a speculation just because the amount of raw material to be available three months hence was a speculation.

Steady Supply of Crude Important

If the supply of crude oil could be kept in line with true demand, the earnings of oil companies would be regularly good from year to year. It would not require any material advance in prices to make them good as new methods decreased costs and markets grew in consuming power. The price of products would be uniform and earnings capable of forecast. Needed replacements and enlargements could be made and still leave a much larger percentage of earnings to be paid out as dividends. All this could become real if only crude supply could be assured but held in restraint to the needs of consumption.

In the early part of 1927 the crude situation became desperate because of the immense production of Seminole County, which was all fine crude with very high gasoline content. The little refiner could top it in quantity and break the gasoline market. He did just that. At the same time new discoveries elsewhere assured a continuous ruinous

overproduction of crude oil for several years unless something was done about it. In desperation and fear of loss, the standard companies, which had lost their long-time transportation advantage through tanker competition, turned to the idea that crude oil could and must be kept in the ground until needed. The company that had been the worst offender at Seminole became the most ardent supporter of conservation. The desperate need of such conservation and the sincerity of the effort since its inception are shown by the changing trend of the oils in relation to other securities from the time of the first tentative agreement at Seminole.

Three Factors That Govern Market Action

From that time the market action of the oil securities has been notable for its lack of attention to the field news of overproduction and the discovery of new fields. It has responded simply to three factors: the condition of the gasoline market, the prospects of conservation and the elimination of false practices in marketing. The year 1928 was made by the gasoline market, which could not have materialized without the Seminole agreements in spite of the shortage of cracking installations. The market of 1929, with continuous growth of strength in the large units of the industry, had no support from the wholesale gasoline situation. The industry enters the year 1930 facing a condition of gasoline production and storage which has little of hope for the immediate future. The strength in the oils has been the reflection of the prospects for conservation, and the development of the code of marketing practices.

The Independent Oil Producer

The fate of the independent oil producer in case of the failure of cooperative movements to control production is indicated in Fig. 2. For this study three groups of five oils each were selected. The first group is made up of Atlantic Refining, Sinclair, Standards of New Jersey and California and Texas Co., which are all coastal refiners and well integrated companies. The second group is Barnsdall, Continental, Philips, Skelly and Mid-Continent, all good large companies, but located near the centers of distress gasoline. The third group is composed of crude producers and landholders; *i. e.*, American Republics, Panhandle, Maracaibo Oil, Producers & Refiners and Texas Pacific Coal & Oil. The high and low average of each group by months is reduced to percentages of the low of January, 1927. Then the highs and lows of the second and third groups are divided by the highs and lows of the first group. The effect is to show the weakness of the second and third groups in relation to the first group.

Since the beginning of 1927, the independent company has been losing ground in relation to the integrated company, because of the distress gasoline which originates in the centers of overproduction of crude

oil. The land speculator was able to keep up hope through the year 1928 but since that time there has come the realization that even good prospective oil land has ceased to be a good investment. Further, there is little indication that the trend of the independent company is changing in relation to the integrated company. On the contrary, the indication is that unless the production of crude oil can be put on a business basis, the industry will gradually work back to the condition that existed before 1911, when the refiner made the money and the producer was the victim.

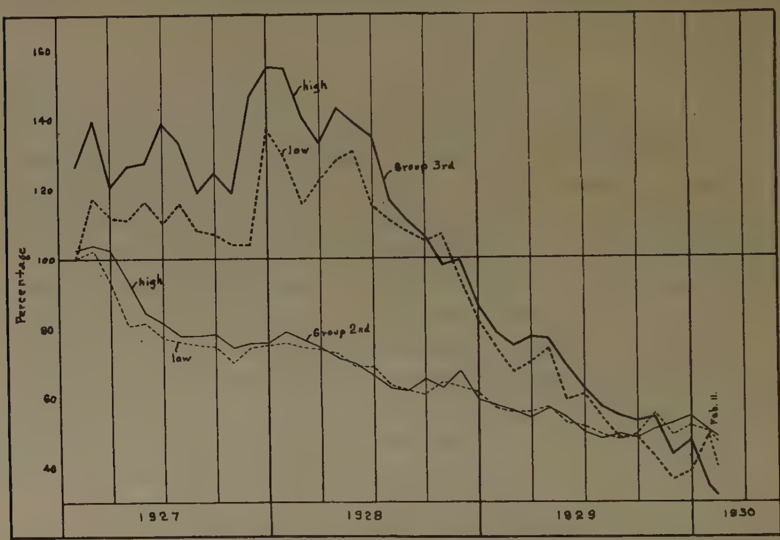


FIG. 2.—PRICE RELATION OF OTHER OILS TO INTEGRATED COMPANIES.

The independent company, the producer and the royalty owner must determine the fate of conservation, and in so doing decide whether they wish continuous profit or a continuation of their private bear market.

DISCUSSION

J. E. THOMAS,* Fort Worth, Texas.—I would like to call attention to an apparent anomaly in Fig. 1, which I take it is due to the fact that the author used Standard Statistics, 1926, as an index. You notice that all his lines came together in 1926. In the preparation of the chart I gave in my paper last year[1] I encountered that same difficulty.

We like to think of the oil business as one of wide variations and great fluctuations, and yet according to that chart, if you decided that the oil business was going rapidly to pot and there was an overproduction or something, instead of selling Standard of New York and Sinclair and Marland, you might just as well have sold U. S. Steel,

* Petroleum Analyst, Fenner & Beane.

[1] J. E. Thomas and M. D. Gould: The Market Price of Oil Securities. *Trans.* A.I.M.E., Petroleum Development and Technology (1928–29) 565.

Anaconda Copper or General Electric. They went down just at the same time and in the same degree. Secondly, if you decided that the oil business was coming into its own, you could just as well have bought one of the coal stocks or New York Central, and the rise was timed at precisely the same month and in exactly the same degree.

If any of you remember the chart I used in my paper last year you will find that for five years, 1920 to 1924 inclusive, the market levels of those stocks moved precisely together. When I tried to bring that up to date in 1929 I found that Standard Statistics were of no use for these indices—the same difficulty Mr. Bryan had; it had a scissors effect. So the true relation is not very well shown by that particular chart. The point is that if he had used 1918 as his mean, instead of having a scissors effect he would have had a wide divergence as in my chart. The oils have not moved down in the last 10 years as you would think from looking at that curve; they are progressively higher.

Furthermore, the bull market of 1922, following the 1921 depression, was participated in by the oils precisely to the same extent as by the others. I therefore must question Mr. Bryan's statement that the oils have been in a bear market since 1919. We had something very much like a bull market from August to November of 1928, which I contended in my paper last year was due to the belief of Wall Street that we oil men had inaugurated a system of control, which we had. But it was not carried far enough, in which I hold that the producer was not to blame; he was deceived by the refiner. But this control did manifest itself in the stock market. It still does, if you analyze it. If you break up your average of 40 oils, some of them are 60 per cent. above the figure of two years ago. Gulf is materially higher than it was two years ago, bearing out what I take to be the main point of Mr. Bryan's paper, that the integrated company is the safest investment. In the oil stocks I go a step farther than that, and I think that the very large integrated company, with a national if not an international geographical integration, is likewise more favorable.

I have a feeling that if a company has holdings in several parts of the country, or of the world, at any given time over a period of years they represent a more stable investment than some well-rounded, thoroughly integrated, nicely balanced, soundly managed little company in just one area.

Production

Production Review for 1929

By C. P. Watson,* Fort Worth, Texas

(New York Meeting, February, 1930)

It is perhaps significant that a few years ago the sessions held here were chiefly occupied with production. In the last two years these sessions have been concerned with production curtailment, unitization and conservation, notwithstanding that production in the United States in 1929 reached a total in excess of 1,000,000,000 barrels.

A study of the leading producing units in the United States shows that Oklahoma, Texas and California in 1929 yielded 84 per cent. of the total production from 33.5 per cent. of the total number of producing wells. Production in the United States in 1929 showed an increase of 107,000,000 bbl. over the 1928 figures.

This increase in itself perhaps is not enough to have caused the serious situation that is now confronting the industry. However, taking into account the gradual encroachment on the consumption of fuel oil through the greater utilization of natural gas, probably we have reached the point in the United States where prices will determine to a large extent, in 1930, the amount that will be produced.

In the states of Texas, Oklahoma and California, the most significant development of 1929 has been the desire of operators to reach some agreement to bring production more or less in control with the estimated demand. In November, production in California, particularly in the Santa Fe Springs field, was drastically cut to meet a certain requirement. Similarly, in Texas, the Yates field has been developed and has been producing under an agreement on the part of the operators; and more recently in Oklahoma City, serious efforts have been made to keep production in line with consumption.

For the year 1930 we can see nothing in sight except drastic curtailment. This is a matter that I am sure is occupying the attention of all the leaders of the industry.

* President, Federal Royalties Co., Inc.

Chapter XIII. Domestic Production

Petroleum Production and Development in Kansas during 1928 and 1929*

By Charles E. Straub† and Anthony Folger,‡ Wichita, Kansas

(New York Meeting, February, 1930)

Kansas produced 38,150,878 bbl. of oil in 1928 and 40,658,170 bbl. in 1929, thereby retaining its rank as fourth among the oil-producing states of this country.

Production for 1928 was less than that for 1927 (Fig. 1) because of a decrease in the number of completions, but the average initial production per well (Table 1) shows an increase due to the completion of wells of comparatively large capacity in the new Valley Center pool of Sedgwick County. This increase in average initial production per well was further augmented during 1929 by completion of additional wells of comparatively large capacity in the Valley Center pool and the new Greenwich pool of Sedgwick County.

Table 1.—*Kansas Completions and Initial Production,* 1920 *to* 1929, *Inclusive*

Year	Total Completion	Total Oil Wells	Total Gas Wells	Total Dry Holes	Dry Holes, Per Cent.	Total Initial Production, Bbl.	Average Initial Production Per Well, Bbl.
1920	3,164	2,327	147	690	21.8	181,845	78.1
1921	1,380	909	118	353	25.6	95,789	105.3
1922	1,640	1,057	86	497	30.3	74,391	70.4
1923	1,405	807	63	535	38.1	61,372	76.0
1924	1,125	650	79	396	35.2	92,668	142.5
1925	2,003	1,281	86	636	31.7	207,880	162.2
1926	2,338	1,458	96	784	33.5	173,664	119.1
1927	1,333	685	79	569	42.8	98,253	143.4
1928	1,157	587	115	455	39.3	101,043	172.1
1929	1,058	553	52	453	42.8	165,611	299.4

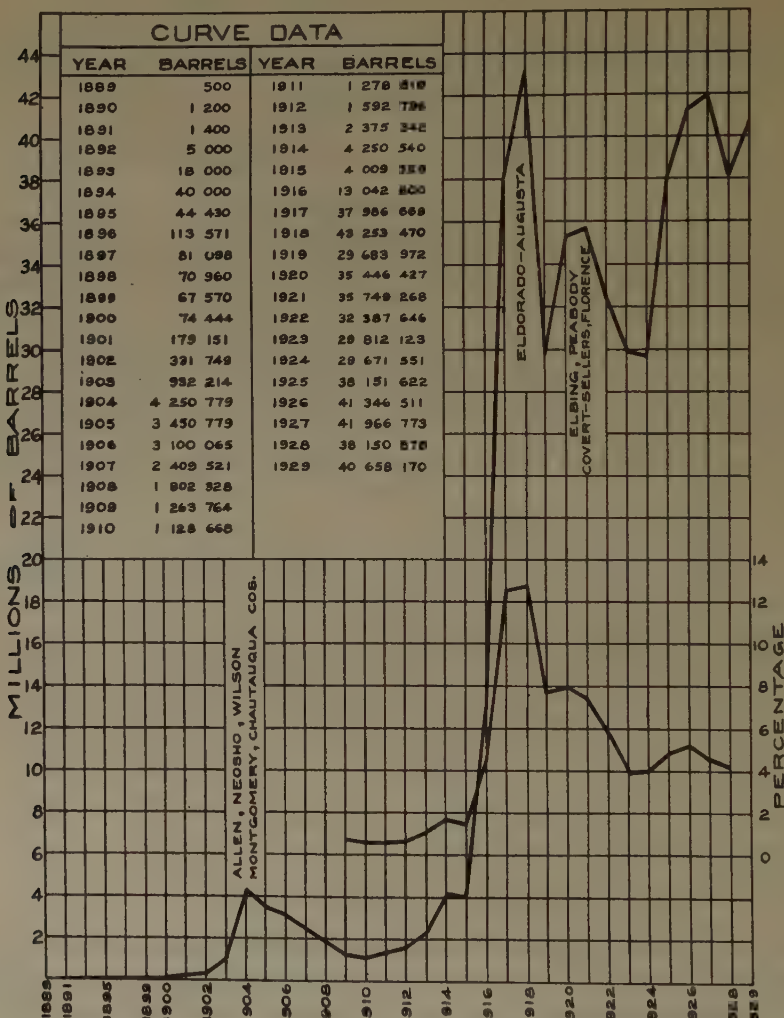
Production for 1929 exceeded that for 1928 and threatened to exceed all records except that of 1918, however, production was prorated in

* Sponsored by Kansas Geological Society.

† Consulting Geologist and Appraiser.

‡ Geologist, Gypsy Oil Co.

October, 1929, to 50 per cent. of the gross potential by operators in the Valley Center pool resulting in a curtailment of approximately 10,000 bbl. per day. This proration continued through the balance of the year and was applied to other new discoveries in McPherson County.



CURVE DATA

YEAR	BARRELS	YEAR	BARRELS
1889	500	1911	1 278 819
1890	1 200	1912	1 592 796
1891	1 400	1913	2 375 342
1892	5 000	1914	4 250 540
1893	18 000	1915	4 009 350
1894	40 000	1916	13 042 800
1895	44 430	1917	37 986 668
1896	113 571	1918	43 253 470
1897	81 098	1919	29 683 972
1898	70 960	1920	35 446 427
1899	67 570	1921	35 749 268
1900	74 444	1922	32 387 646
1901	179 151	1923	28 812 123
1902	331 749	1924	28 671 551
1903	932 214	1925	38 151 622
1904	4 250 779	1926	41 346 511
1905	3 450 779	1927	41 966 773
1906	3 100 065	1928	38 150 570
1907	2 409 521	1929	40 658 170
1908	1 802 328		
1909	1 263 764		
1910	1 128 668		

FIG. 1.—PETROLEUM PRODUCTION IN KANSAS, 1889 TO 1929 INCLUSIVE, AND PERCENTAGE OF ANNUAL PRODUCTION OF THE UNITED STATES.

Competitive drilling for flush production in the Valley Center pool by the use of rotary equipment, an innovation for Kansas operators, hastened development and no doubt accounts for part of the large flush production in the new pools of Sedgwick County. Rotary equipment

is also being used in the Voshel pool of McPherson County and the State line pool of Sumner County.

It is significant of the type of oil encountered that the average weighted gravity of Kansas crude was higher than that of any other state in the Mid-Continent field during 1929. This fact together with the relatively lesser drilling depths at which production is found, better operating conditions than found elsewhere, reasonable recoveries per acre versus costs, and the large potential areas as yet undeveloped has caused the major companies to become extremely active in Kansas; practically all of those of the North Mid-Continent area and some from the South having offices at Wichita, Kansas.

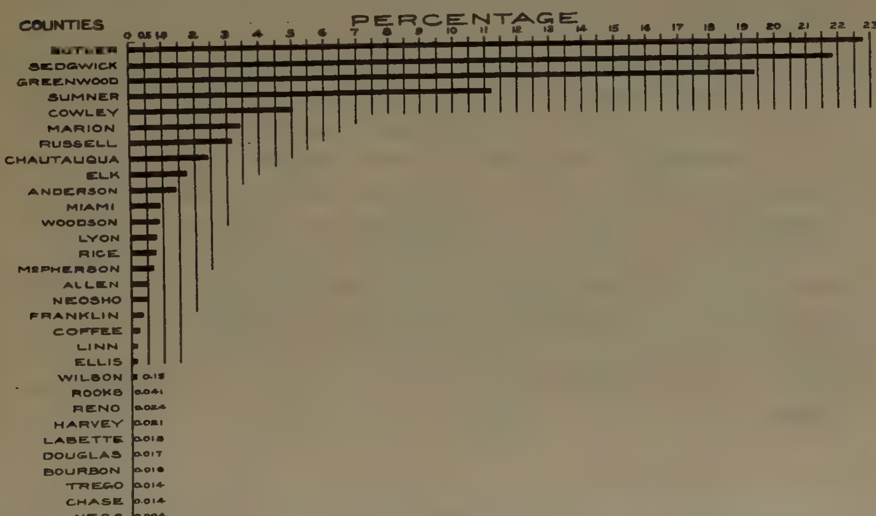


FIG. 2.—PERCENTAGE CONTRIBUTION OF VARIOUS COUNTIES TO KANSAS 1929 PETROLEUM PRODUCTION.

Wildcatting was at its height for Kansas about the middle of the year 1929. There were approximately 50 counties active, 40 of which are in Central and Western Kansas. Sedgwick County led in drilling operations, Greenwood ranked second and Butler third.

Fig. 2 shows the rank of the producing counties for 1929. Greenwood led in production for 1927 and 1928, with Butler ranking second and Sumner third. Sedgwick County which ranked second for 1929 would have been first had it not been for proration in the Valley Center pool.

The principal producing pools were the Churchill-Oxford of Eastern Sumner County for 1928 and the Valley Center pool of Sedgwick County for 1929. Approximately one-fifth of the total production of the state came from the latter during 1929.

For detailed consideration of development, the state is divided into Eastern and Western Kansas, the latter comprising all those counties

that have all or most of their areas in ranges west of the sixth principal meridian.

EASTERN KANSAS

Northeastern Kansas.—The outstanding development of this Shoestring area during 1928 was the continued development of the Big Lake pool of Miami County in T. 16 S., R. 24 E.; the finding of a new Upper Bartlesville sand pool centered about sec. 4, T. 21 S., R. 21 E., of Anderson County; the "drilling up" of the Blue Mound gas field located in the northeastern part of T. 22 S., R. 22 E. and the western part of T. 22 S., R. 23 E., Linn County; and the development of the shale gas in Miami and Johnson counties.

During 1929 Bartlesville sand oil and gas pools similar to that developed in 1927 were again opened in T. 22 S., R. 21 E. and in T. 21 S., R. 21 E., Anderson County; a new pool was developed in T. 17 S., R. 25 E., Miami County; a new Bartlesville sand gas pool opened in T. 17 S., R. 20 E., Franklin County; and a gas pool was developed in the Bush City sand in T. 21 S., R. 21 E., of Anderson and Linn counties.

Shale gas was further developed during 1929 in Miami and Johnson counties and adjacent parts of Missouri, that on the Fairfax Airport at Kansas City being of considerable importance; the wells having an open flow capacity up to 1,500,000 cu. ft. at depths ranging from 340 to 370 feet.

Table 2 gives such details as are available concerning these developments.

TABLE 2.—*Development and New Discoveries in Northeastern Kansas Shoestring Area*

County	Location	Development Period	Producing Sand	Depth Range, Ft.	Sand Thickness, Ft.	Initial Production, Cu. Ft. or Bbl.	Gravity	Wells Producing
Johnson..	Fairfax Airport	1929		340 to 370		1,000,000 to 1,500,000	Gas	14
Miami ...	29 to 14-16-24	1927 to 1928	Big Lake	325 to 400		20 to 250		
Miami ...	6-17-25	1929	Big Lake	375 to 400				15
Miami ...	1-17-23	1929		418	25	gas and oil	34°	3
Linn	14, 23, 26-21-21	1929	Bush City	570 to 620	50	1,000,000	Gas	35
Anderson.	15, 22-21-21		Oil sand					
Linn	N. E. 22-22 W. 22-23	1927 to 1928	Lower Cherokee	650 to 700		250,000 to 4,500,000	Gas	75
Anderson.	About 4-21-21	1928	Upper Bartlesville	700	0 to 50	10 to 75	34°	35
Anderson.	9, 16, 21-22-21	1929	Bartlesville	715 to 750	25	120		12
Anderson.	10, 15-21-21	1929	Bartlesville	650 to 750	40	100 to 200	33°	30
Franklin .	6-17-20	1929	Bartlesville	720 to 760		1,000,000	Gas	12

TABLE 3.—*Development and New Discoveries in Southeastern Kansas*

County	Location	Development Period	Producing Sand	Depth Range, Ft.	Sand Thickness, Ft.	Initial Production, Bbl. or Cu. Ft.	Gravity	Wells Producing
Woodson	8-24-17	1928	Big Lime	325			Gas	
Woodson	31-23-16	1928	Mississippi lime	1,500		25		
Coffey	13-23-14	1929	Mississippi lime	1,600	30			
Bourbon	23, 26-23-21	1929	Bartlesville	600 to 650		50 to 100	27°	
Labette	32-19	1928	Oswego shale	150 to 750		500,000 to 1,000,000	Gas	100 to 150
	33-18 and 19		Bartlesville			100,000 to 1,000,000	Gas	
	34-18 and 19		Mississippi lime			100,000 to 3,000,000	Gas	
Labette	32-17 and 18	1928	Oswego, Bartlesville and Mississippi lime	Deeper			Gas	
Montgomery	5, 6, 8-34-15	1928	Bartlesville			250,000	Gas	10 or 12
Montgomery	17, 18, 19, 20-34-15	1928	Wayside	500		5		15 to 20
Montgomery	32-33-15 and 5-34-15	1928	Bartlesville	1,000		?	?	
Montgomery	34-13	1928	Redd oil					
			Mississippi gas					
Chautaqua	33-12	1927 to 1929	Peru	900		30	34 to 35°	23
Elk	Moline town site	1928 to 1929	Mississippi oil	1,980	35 to 40	100	36 to 37°	33
	9, 10, 15, 16-31-10	1927 to 1928	Encill	1,150			Gas	3
Elk	3-31-8	1928	Kansas City	1,920 to 1,975		600 to 700	36°	Oil 3
Elk	12-31-8	1929	Encill	1,505 to 1,515		14,000,000	Gas	
Elk	35, 36-31-10	1928	Oswego oil	1,550		130		1
			Mississippi gas	2,000		600,000 to 1,000,000	Gas	
Elk	34-29-12	1928	Top Kansas City	800				
Elk	12, 13-29-8	1928	Wilcox			Small		2
Elk	9-29-9	1929	Wilcox	2,640		80	33°	1

Southeastern Kansas.—The principal developments for 1928 and 1929 in Southeastern Kansas were: the Oswego shale, Bartlesville sand and Mississippi lime gas pools in T. 32 S., R. 19 E., T. 33 and 34 S., R. 18 and 19 E.; T. 32 S., R. 17 and 18 E., Labette County; the extension of an old Bartlesville oil pool in T. 23 S., R. 21 E., Bourbon County; the continued development of the Peru sand oil pool in T. 33 S., R. 12 E., Chautaqua County; and the discovery and development of the Mississippi lime pool of the Moline town site, Elk County.

Table 3 gives such details as are available relative to these developments and others of minor importance.

Marion County

Lost Springs Field.—The area in T. 17 S., R. 4 E., centering around the Lost Springs town site, reached its peak in development and production during the first half of 1928. Thirty producers had been added to the six completed in 1927, giving a maximum daily average of 2035 bbl. Since that time production has been steadily declining and in December, 1929, averaged 633 bbl. The field produced 530,024 bbl. in 1928 and 299,815 bbl. in 1929.

Oil production from the field is confined to irregularly eroded residual cherts of the Mississippi lime found at about 2400 ft. The penetration of the producing "chat" varies from practically nothing to 70 ft. Several tests have been carried to the "Siliceous" lime in the township and have been uniformly water-bearing.

Hillsboro Field.—In September, 1928, a well in sec. 7, T. 19 S., R. 3 E. was completed in the chat at the top of the Mississippi lime with an initial production of 8,250,00 cu. ft. of gas and 162 bbl. of oil of 42° gravity at a depth of 2425 to 2458 ft. The three offsets were dry and one of them was immediately carried to the Ordovician where oil of 34° gravity was found in the upper 20 ft. of a dolomitic lime at a depth of approximately 2800 ft. Fifteen producers have been completed in this dolomitic lime to date with an initial production ranging from 75 to 400 bbl.

The pool attained a daily average production of 1188 bbl. in August, 1929, and produced 256,038 bbl. during the year. Its discovery was due to the previous finding of a favorable structure by core drilling.

Area North of Marion County.—During 1928 a brisk wildcatting campaign was carried on in Dickenson and Western Morris counties with the object of uncovering chat production of the Lost Springs type. Frequent shows of oil in the top of the chat were encountered, and one small producer in sec. 30, T. 17 S., R. 5 E. Riley, Clay, and Geary counties were on the outside fringe of this activity, and in sec. 21, T. 9. S., R. 4 E. a well good for 60 bbl. of 31° gravity oil was completed

and is of interest chiefly because it indicates that chat pools may eventually be found in this general area.

Four gas wells were completed in sec. 10, 15 and 16, T. 16 S., R. 7 E., Morris County at a depth of approximately 500 ft. with volumes up to 1,000,000 cu. ft. A shallow gas sand at approximately 490 ft. is also producing in sec. 21, T. 17 S., R. 7 E.

Lyon and Chase Counties

In July, 1929, a 400-bbl. well was completed in NW. of SW. sec. 19, T. 20 S., R. 10 E. at a depth of 2175 to 2240 ft., extending the Bartlesville sand trend of southwestern Lyon County three-fourths of a mile. A 25-bbl. offset was completed across the line in Chase County. A small producer in NE. of SE. sec. 30, T. 20 S., R. 10 E. was also encountered in the same trend at a depth of 2304 to 2385 feet.

Greenwood County

Lamont Pool.—This pool discovered in 1927, was developed rapidly during 1928 and 1929 and now extends in a northwest southeast direction for 3 miles through sec. 23, 24, 26, 25, T. 22 S., R. 12 E., sec. 29, 30, 32, T. 22 S., R. 13 E., adjacent to and partly including the town site of Lamont. Over 100 producing wells have been drilled having an average initial production of 300 bbl. of 40° gravity oil found in a Bartlesville sand trend at depths of approximately 1650 ft. The pool had a daily average of 4330 bbl. and produced 1,579,000 bbl. during 1928. Expected recovery per acre is 7000 barrels.

Norton Pool.—The Norton pool, discovered in April, 1929, is located in sec. 15 and 22, T. 22 S., R. 12 E., and appears to be a connecting link in a sand trend between the producing Bartlesville area northeast of Madison and the Lamont pool. Nine producing wells with an average initial production of 109 bbl. of 41° gravity oil have been completed in the Bartlesville sand found at depths slightly in excess of 1700 ft. Water is present in the lower part of the sand body and is significant in that the ultimate recovery will probably be low.

Demalorie-Souder Extension.—During 1928 four additional Bartlesville sand wells were completed in the west extension of this important pool with initial production of approximately 150 bbl. each at depths of 2150 ft. Explorations to further extend the pool have failed.

Edwards Extension.—Efforts to extend the Edwards pool, located in T. 23 S., R. 11 E., were only partly successful in 1928, however, during 1929, 33 producing wells were completed in sec. 21, 22, 27 and 28 with an average initial production of 304 bbl. of 42° gravity oil. As with most of the important pools of Greenwood County production is from the Bartlesville sand, found at a depth of about 1900 ft. in this area. This

extension is of importance due to the well saturated condition of the sand which attains a thickness of 90 ft., the sustained nature of the production and the possibility that it may connect with the Patterson pool to the southeast. An ultimate yield of 7000 bbl. per acre may be expected.

Patterson Pool.—This pool was opened by the discovery of Bartlesville production at a depth of about 1765 to 1837 ft. in a well located in sec. 36, T. 23 S., R. 11 E. near Hamilton and has recently been extended into sec. 1, T. 24 S., R. 11 E. Ten wells have been completed with an average initial production of 357 bbl. of 41° gravity oil. A recovery of 7000 bbl. per acre may be expected.

Quincy and Hoggett Pools.—Just east of the town of Quincy in T. 25 S., R. 13 E. Bartlesville sand production was discovered in November, 1927, which was thought to have excellent possibilities, but efforts during 1928 resulted in the completion of only seven producers and an equal number of dry holes. The sand was found at a depth of about 1400 ft. The oil is of 38° gravity and recovery will not exceed 2500 bbl. per acre.

Near Quincy in sec. 9, T. 25 S., R. 13 E. a Bartlesville sand well was completed, in July, 1929, with an initial production of 50 bbl. of 37° gravity oil, and at a total depth of 1535 ft. Ten wells have been completed with an average initial production of 102 bbl. The decline has been rapid.

Miscellaneous.—During 1928 several wells were completed in what is locally known as the "Cattlemen's sand," at about the Bartlesville horizon and at a depth of 2200 ft. in sec. 6, T. 25 S., R. 9 E., Olsen pool. A few wells were completed as producers from the Mississippi lime at depths of about 1600 ft. in the Virgil area of eastern Greenwood County during 1929.

Butler County

Haverhill Pool.—This field was discovered in April, 1927, and has received continued development during 1928 and 1929. Twenty-four producing wells were completed in 1928 with an average initial production of 198 bbl. and 29 in 1929 with an average initial of 126 bbl., making a total of 45 wells. The field is at present 3 miles long trending through sec. 22, 27, 34, T. 27 S., R. 5 E., and is one-fourth to one-half mile in width. The oil is 40° gravity and is found in a Bartlesville sand trend at a depth of approximately 2700 ft. Recovery will be approximately 4000 bbl. per acre.

Sluss Pool.—This narrow Bartlesville sand trend located in sec. 5, 6, T. 27 S., R. 6 E., was discovered in March, 1928. At the end of the year there were about 25 wells, which had initial productions of 200 to 500 bbl. of 39° oil. The Bartlesville is at a depth of about 2700 ft. By the end of 1928 the pool had produced 490,000 bbl. but during 1929 declined rapidly due to close drilling. Five other wells were completed during 1929. The

recovery is expected to exceed 7000 bbl. per acre. Two wells have been completed in the Viola lime of Ordovician age.

Shaffer Pool.—Development in this pool located in sec. 3, 4, 8, 9, 10, T. 27 S., R. 6 E. was carried forward into sec. 8. 9, 10 during 1928. Fifteen wells were completed in the Viola lime (Ordovician) at a depth of about 3150 ft. with initial averaging 150 bbl. Five others were completed during 1929 in the Viola averaging 67 bbl. and four in the top of the Mississippi at a depth of about 2750 ft., averaging 54 bbl. Most of the Viola lime wells showed considerable oil in the top of the Mississippi. The gravity is 36° and the recovery is expected to exceed 7000 bbl. per acre.

Eldorado Field.—Almost 100 wells were completed during 1928 in the 650-ft. sand (Admire) of the Eldorado field in sec. 19, 20, 30 T. 25 S., R. 5 E., averaging 20 bbl. initial of 36° gravity oil. During 1929 in the above sections and in sec. 24, 25, 36, T. 25 S., R. 4 E., about 75 others were completed with an average initial of 25 bbl. Recovery is expected to be approximately 2000 bbl. per acre.

Development of the deep pay in the Eldorado field was carried on by the completion of 25 wells in sec. 18, 19, 20 T. 26 S., R. 5 E. for an average initial production of 130 bbl. of 35° gravity oil from the Viola and "Wilcox" sand at approximately 2600 ft. on inside proven areas. Recovery of 7000 bbl. per acre is expected from these wells.

Miscellaneous Discoveries.—During 1928, several Mississippi chat wells were completed in the vicinity of the Pierce discovery well located in sec. 28, T. 25 S., R. 4 E. with initial production of about 50 bbl. of 43° gravity oil at a depth of about 2600 feet.

Chat production was also encountered at a depth of 2765 ft. near Benton in sec. 10, T. 26 S., R. 3 E. The discovery well had an initial production of 450 bbl., but the offsets were practically dry and one tested the Ordovician series below without securing production.

What was thought to be an important discovery well was completed during 1929 in sec. 24, T. 27 S., R. 4 E. as a 210-bbl. producer of 41° gravity oil from the Wilcox sand found at a depth of 3012 to 3022 ft. The offsets were smaller wells and efforts to extend the producing area have failed beyond a quarter mile.

Cowley County

The most important development in 1928 took place in the State Home pool adjoining Winfield on the north and located in sec. 9, 10, 15, 16, 22, T. 32 S., R. 4 E. Ten wells were producing from the Layton sand (2300-ft. sand) during 1928, but four of these were deepened to lower sands which are the Bartlesville (Rainbow Bend sand) found at a depth of about 3000 ft., and the Siliceous lime (Ordovician) at about 3300 ft. Development of the pool continued during 1929 and good wells were completed in the Siliceous lime but the pool is now defined.

The Bartlesville sand production of the East Winfield pool found at a depth of about 3050 ft. was extended a quarter mile east in sec. 19, T. 32 S., R. 5 E. during 1929.

The Smith pool that is producing from the Bartlesville at about 3000 ft. in sec. 10, T. 31 S., R. 3 E. was extended into sec. 15 during 1929.

In the Burden area of T. 31 S., R. 6 E. several Bartlesville wells were completed in sec. 30 during 1929 at a depth of about 3000 ft., having initial production of 25 to 200 bbl.; and in sec. 20 a good well producing from the same sand was encountered at about 2900 ft. A gas well estimated to have an open flow of 40,000,000 cu. ft. at 1640 ft. and 68,000,000 cu. ft. at 2215 ft. was encountered in the NE. corner of the same section, but has been "mudded off" to test lower sands for oil. Another well has since been drilled in the center of the same 40-acre tract, the first gas missed, but about 16,500,000 cu. ft. was encountered in the 2200-ft. sand with a rock pressure of about 800 pounds.

In sec. 18, T. 30 S., R. 5 E. a Bartlesville sand well was completed at a depth of 2850 to 2900 ft. with an initial production of 100 bbl. This well is northeast of the old Rock pool.

Development of the helium gas areas in the vicinity of Dexter continued during 1928 and 1929, the wells having open-flow capacities up to 500,000 cu. ft., containing 2 per cent. helium.

Western Kansas

Between Jan. 1, 1924 and Dec. 31, 1929, the recovery of oil from western Kansas has been 17,186,965 bbl. from 13 counties. Eleven of these counties are now actively producing. The per county recovery has been as follows:

County	Production, Bbl.	Number of Wells	Age of Oldest Production, Years
Sedgwick (ranges West)	7,420,821*	113	2
Russell	7,025,211	158	6
Rice	1,660,144	28	6
McPherson	490,145	20	2
Sumner (ranges West)	389,972	11	3
Ellis	69,222	7	1
Rooks	57,187	4	3
Reno	33,121	1	3
Kingman (abandoned in 1927)	27,000	1	2
Trego	8,004	1	1
Edwards	3,177	1	1
Ness	1,660	1	1
Harvey (abandoned in 1929)	1,301	1	1
	17,186,965	347	

* Includes all of Valley Center field.

During 1928, 2,127,178 bbl. of oil were produced in western Kansas as against 1,703,005 bbl. in 1927. The annual production in 1929 was 9,608,402 bbl. The cause of this increase was chiefly the Valley Center field of Sedgwick County.

The oil produced in western Kansas is derived from eight horizons. The age of these horizons, together with the total amount of oil recovered from each, appears in the following table:

Producing Horizon	Production, Bbl.	Age	Number of Wells	Age of Oldest Production, Years
Simpson dolomite	7,418,474	Ordovician	112	2
Oswald series	6,359,322	Pennsylvanian	151	6
Mississippi lime	2,099,428	Mississippian	45	6
Pennsylvanian basal conglomerate	753,419	Pennsylvanian	19	2
Wilcox sand	378,598	Ordovician	7	2
Kansas City formation	111,454	Pennsylvanian	9	3
Siliceous lime	63,210	Ordovician	6	1
Viola lime	3,060	Ordovician	1	1
	17,186,965			

The total volume of gas produced in western Kansas to the close of 1929 has been 10,741,078,000* cu. ft., from the following five horizons:

Producing Horizon	Production, Cu. Ft.	Age	Number of Wells	Year Discovered	Year of First Active Production
Mississippi lime	8,713,226,000	Mississippian	18	1926	1927
Pennsylvanian basal conglomerate	884,853,500	Pennsylvanian	7	1927	1929
Howard lime and Severy shale	665,054,000	Pennsylvanian	4	1928	1928
Topeka lime†	477,945,000	Pennsylvanian	3	1927	1927
Chase formation		Permian	4	1922	1929

A complete record of the production of oil in western Kansas during 1928 and 1929 appears in Table 4. A summary of its oil and gas development from January, 1924, to Dec. 31, 1929, will be found in Table 5. This summary presents a record of every locality in western Kansas which is producing, or has produced, oil or gas in commercial quantities.

Development.—A total of 900 wells, drilled for oil or gas, have been completed in western Kansas, ranges 1 to 43 West, to the close of 1929.

* Total incomplete.

† No production during 1929.

Of this number, 300 have produced oil and 45 are either producing or capable of producing gas, making a total of 345 producing wells, or 38 per cent. of the total number of wells drilled. Oil has been recovered from 29 fields of which 27 are producing actively at the present time. Gas has been found in 12 localities, of which 11 were yielding gas at the end of the year. The relationship between producing wells and dry holes during the last three years is as follows:

TABLE 4.—*Petroleum Production by Fields in Western Kansas, Ranges 1 to 43 West, 1928 and 1929*

Fields	Production, 1928, Bbl.	Production, 1929, Bbl.
Russell County:		
Fairport	617,314	501,365
South Fairport	72,319	256,790
North Fairport	4,756	20,954
Gorham	571,442	462,823
North Gorham	7,314	8,476
Susank		27,910
Ochs lease		4,126
Total	1,273,145	1,282,444
Ellis County:		
Yocemento		23,697
North Ellis		45,525
Total		69,222
Trego County		8,004
Rooks County	25,102	24,256
Ness County		1,660
Edwards County		3,177
Rice County:		
Welch	446,202	279,373
Schurr lease		11,490
Total	446,202	290,863
Reno County	8,136	9,490
McPherson County:		
McPherson	28,552	67,585
Ritz		315,333
Voshell		70,857
Grattin lease		7,818
Total	28,552	461,593
Harvey County		1,301
Sumner County:		
Love and Latta lease	22,438	45,188
Jewel Douglas lease	21,270	3,417
Caldwell		286,114
Peasel lease		3,185
Total	43,708	337,904
Sedgwick County:		
Valley Center	302,333	7,105,110
Cross lease		2,347
Curry lease		11,031
Total	302,333	7,118,488
Gross production	2,127,178	9,608,402

WESTERN KANSAS DEVELOPMENT, RANGES 1 TO 43 WEST

	1927	1928	1929*	Grand Total, 1905 to 1929
Total completions	117	106	277	900
Oil wells	30	36	122	300
Gas wells	6	22	13	45
Total oil and gas wells	36	58	135	345
Dry holes	81	48	142	555
Percentage of producing wells to total completions	30	54	48	38

* The figures for 1929 do not include those wells completed in sec. 6 and 7, T. 26 S., R. 1 E., of the Valley Center field.

The only counties receiving special discussion here will be those in which the discovery of oil during the 1928–1929 period has been of greatest economic significance. For a complete summary of the oil and gas produced in western Kansas to the close of 1927 the reader is referred to an article by L. W. Kesler.[1] All information relative to oil and gas wells, completed in western Kansas during 1928 and 1929, and not included in the following county discussion, appears in Tables 4 and 5.

Ellis County

Commercial production was first found in Ellis County during 1928 by Phillips Petroleum Co. in its No. 1 Shutts, in the center NE. ¼ of sec. 5, T. 12 S., R. 17 W., from 3569 to 3575 ft. The top of the "Oswald" lime was reached at 3331 ft., so that the producing horizon is 238 ft. below the top of the Oswald lime and occurs in the top of the Siliceous lime. The well was completed in the early part of December, 1928, and a 17-hr. gage yielded 205 bbl. of oil, or at the rate of 290 bbl. per day. The gravity is 33.5° Bé. at 64° F. No oil showings were encountered in the Oswald series.

North Ellis Field.—The discovery well of this field, Phillips Petroleum Co. No. 1 Shutts, in sec. 5, T. 12 S., R. 17 W., was completed in December, 1928. The details of its initial production appear above. Following are the wells comprising the field, listed order of completion:

Name	Location	Status	Pay, Ft.	Producing Horizon
Phillips Petroleum Co., No. 1 Shutts.........	S. 5, T. 12 S., R. 17 W.	Producing	3569 to 3575	Siliceous lime
Burgher Oil Co., No. 1 Hadley.............	S. 20, T. 11 S., R. 17 W.	Shut in	3428 to 3440	Pennsylvanian basal conglomerate
Phillips Petroleum Co., No. 2 Shutts.........	S. 5, T. 12 S., R. 17 W.	Producing	3635 to 3638	Siliceous lime
Phillips Petroleum Co., No. 1 Weigel........	S. 19, T. 12 S., R. 17 W.	Producing	3683 to 3686	Pennsylvanian basal conglomerate
Phillips Petroleum Co., No. 1 Schmeidler.....	S. 20, T. 12 S., R. 17 W.	Abandoned	None	

Despite the fact that as much as 3 miles separates some of these wells, they are all situated on the same line of folding and are, at least for the present, considered as forming one field. Production is found in the Siliceous lime and Pennsylvanian basal conglomerate. The wells have an initial production of 300 bbl. of 32° Bé. oil. Actual producing of the North Ellis field did not commence until July, 1929, and in 6 months it has yielded 45,525 bbl. from three wells. The amount of Siliceous lime production has been 43,132 barrels.

[1] L. W. Kesler: Oil and Gas Resources of Kansas in 1927. Min. Resources *Circ.* 1, State Geol. Survey of Kansas, **29**, No. 11, 31.

TABLE 5.—*Oil and Gas Development of Western Kansas, January, 1924, to December, 1929*

Name of Field	Location	County	Discovery Date	Number of Wells Producing Dec. 1929	Average Depth, Ft.	Production, 1928, Bbl.	Production, 1929, Bbl.	Total Production Since Discovery, Bbl.	Gravity	Producing Horizon
Active and Abandoned Oil-producing Areas										
Lewis	S. 31, T. 25 S., R. 17 W.	Edwards	May 22, 1929	1	4,545		3,177	3,177	35°	Pennsylvanian basal conglomerate
North Ellis	S. 20, T. 11 S., R. 17 W. S. 5 & 19, T. 12 S., R. 17 W.	Ellis	December, 1928	3	3,428 to 3,683		45,525	45,525	33°	Pennsylvanian basal conglomerate and Siliceous lime Ordovician
Yocemento	S. 9, T. 13 S., R. 19 W.	Ellis	June 17, 1929	4	3,590		23,697	23,697	35°	132-ft. pay of Oswald series Pennsylvanian
Halstead	S. 11, T. 23 S., R. 2 W.	Harvey	August, 1928	1	3,005		1,301	1,301 (Abd. Nov. 2, 1929)	29°	Mississippi lime
Kingman	S. 16, T. 27 S., R. 7 W.	Kingman	Jan. 25, 1926	1	3,876			27,000 (Abd. Sept., 1927)	31°	Mississippi lime
Grattin lease	S. 34, T. 20 S., R. 3 W.	McPherson	Oct. 28, 1929	1	3,093		7,818	7,818	36°	Mississippi lime
McPherson	S. 31 & 32, T. 18 S., R. 2 W.	McPherson	July 7, 1928	7	2,975	28,552	67,585	96,137	37°	Mississippi lime
Ritz	S. 1 & 12, T. 20 S., R. 2 W.	McPherson	December, 1928	7	2,970		315,333	315,333	36°	Mississippi lime
Voshell	S. 9 & 10, T. 21 S., R. 3 W.	McPherson	August, 1929	5	3,300		70,857	70,857	42°	Misener sand Viola lime Wilcox sand
Aldrich lease	S. 7, T. 18 S., R. 25 W.	Ness	October, 1929	1	4,428		1,660	1,660	33°	Ordovician Siliceous lime
Abbeyville	S. 24, T. 24 S., R. 8 W.	Reno	Jan. 1, 1927	1	3,540	8,136	9,490	33,121	37°	Basal Kansas City Pennsylvanian
Schurr lease	S. 21, T. 20 S., R. 10 W.	Rice	August, 1929	1	3,278		11,490	11,490	55°	Pennsylvanian basal conglomerate
Welch	S. 34 & 35, T. 20 S., R. 6 W. S. 2 & 3, T. 21 S., R. 6 W.	Rice	April, 1924	27	3,375	446,202	279,373	1,648,654	32°	Mississippi lime
Laton	S. 11 & 14, T. 9 S., R. 16 W. S. 3, T. 10 S., R. 16 W.	Rooks	July 5, 1927	2	3,125 to 3,320	25,102	24,256	57,187	32°	30, 45, and 98-ft. pays of Oswald series Pennsylvanian

Fairport	S. 29 & 30, T. 11 S., R. 15 W. S. 5, 7, 8, 17 & 18, T. 12 S., R. 15 W.	Russell	Nov. 24, 1923	100	2,950 to 3,300	617,314	501,365	5,478,978	40°	Nine Pays in Oswald series, Pennsylvanian
Gorham	S. 32 & 33, T. 13 S., R. 15 W. S. 4 & 5, T. 14 S., R. 15 W.	Russell	Oct. 15, 1926	26	3,055 and 3,317	571,442	462,823	1,108,048	34° and 37°	30, 45 and 65-ft. pays of Oswald and Pennsylvanian basal conglomerate
North Fairport	S. 9, 20 & 29, T. 11 S., R. 15 W.	Russell	June 14, 1928	4	3,073 to 3,204	4,756	20,954	25,710	38 to 42°	30, 190 and 220-ft. pays of Oswald series, Pennsylvanian
North Gorham	S. 7, T. 13 S., R. 15 W.	Russell	June, 1927	1	3,100	7,314	8,476	22,601	39°	Five Pays in Oswald series, Pennsylvanian
Ochs lease	S. 23, T. 15 S., R. 14 W.	Russell	Oct. 14, 1929	1	3,364		4,126	4,126	36°	Pennsylvanian basal conglomerate
South Fairport	S. 30 & 31, T. 12 S., R. 15 W. S. 25 & 36, T. 12 S., R. 16 W. S. 6, T. 13 S., R. 15 W. S. 1, T. 13 S., R. 16 W.	Russell	March 13, 1926	21	3,030	72,319	256,790	357,838	40°	Four Pays in Oswald series, Pennsylvanian
Susank	S. 16, T. 15 S., R. 13 W.	Russell	June 20, 1929	3	3,360		27,910	27,910	38°	Pennsylvanian basal conglomerate and Siliceous lime
Cross lease	S. 27, T. 25 S., R. 1 W.	Sedgwick	April, 1929	1	2,690		2,347	2,347	35°	Middle Kansas City Formation, Pennsylvanian
Curry lease	S. 2, T. 27 S., R. 1 W.	Sedgwick	October, 1929	1	3,389		11,031	11,031	41°	Simpson Dolomite, Ordovician
Valley Center	S, 36, T. 25, R. 1 W. S. 1 & 12, T. 26 S., R. 1 W. S. 6 & 7, T. 26 S., R. 1 E.	Sedgwick	Aug. 21, 1928	111	3,375	302,333	7,105,110	7,407,443	43°	Misener sand, Mississippian and Simpson dolomite, Ordovician
Caldwell	S. 16, T. 35 S., R. 3 W.	Sumner	April, 1929	2	4,778		286,114	286,114	47°	Wilcox sand, Ordovician
Douglas lease	S. 23, T. 34 S., R. 2 W.	Sumner	July, 1927	1	4,492	21,270	3,417	24,687	46°	Wilcox sand, Ordovician
Love & Latta lease	S. 9, T. 30 S., R. 2 W.	Sumner	June, 1927	7	3,040	22,438	45,188	75,986	40°	At Top and Base of Kansas City, Pennsylvanian
Wellington	S. 33. T. 31 S., R. 1 W.	Sumner	Dec. 4, 1929	1	3,656		3,185	3,185	43°	Mississippi lime
Rega	S. 20, T. 13 S., R. 21 W.	Trego	May 19, 1929	1	3,960		8,004	8,004	35°	Pennsylvanian conglomerate
Grand Total				343		2,127,128	9,608,402	17,186,965		

TABLE 5.—(*Continued*)

Active Gas-producing Areas

Name of Field	Location	County	Discovery Date	Date First Active Production	Number of Wells Producing Dec., 1929	Depth, Ft.	Production, 1928, Cu. Ft.	Production, 1929, Cu Ft.	Total Production, Cu. Ft.	Producing Horizon
Medicine Lodge.	S. 11, 12, 13 & 14, T. 33 S., R. 13 W.	Barber	January, 1927	1929	4	4,441–4,558		471,930,000	471,930,000	Pennsylvanian basal conglomerate
Morrison lease.	S. 21, T. 32 S., R. 21 W.	Clark	November, 1928	Aug. 15, 1929	1	5,443		62,000,000	62,000,000	Pennsylvanian basal conglomerate
Lewis..........	S. 31, T. 25 S., R. 17 W.	Edwards	May 22, 1929	Oct. 23, 1929	1	4,545		147,276,500	147,276,500	Pennsylvanian basal conglomerate
Halstead.......	S. 11, T. 23 S., R. 2 W.	Harvey	August, 1928	August, 1928	2	2,968	9,826,000	87,842,000	97,668,000	Mississippi lime
Galva..........	S. 11, T. 19 S., R. 2 W.	McPherson	July, 1929	1929	3	2,892		749,874,000	749,874,000	Mississippi lime
McPherson.....	S. 29, 30, 31 & 32, T. 18 S., R. 2 W.	McPherson	September, 1926	January, 1927	13	2,855–2,973	2,705,327,000	4,216,722,000	7,670,049,000	Mississippi lime
Ritz...........	S. 12, T. 20 S., R. 2 W.	McPherson	Dec. 28, 1928	1929	1	2,927		195,644,000	195,644,000	Mississippi lime
La Crosse......	S. 27, T. 17 S., R. 17 W.	Rush	Nov. 4, 1928	April 1, 1929	1	3,575		203,647,000	203,647,000	Pennsylvanian basal conglomerate
Liberal.........	S. 20, T. 33 S., R. 33 W. S. 3, T. 35 S., R. 34 W.	Seward	December, 1922	1929	2	2,645–2,750		?	?	Big Blue Group—Permian
Hugoton.......	S. 29, T. 33 S., R. 36 W. S. 31, T. 33 S., R. 38 W. S. 10, T. 33 S., R. 37 W. S. 3, T. 35 S., R. 38 W.	Stevens	May, 1927	1929	3	2,500–2,805		?	?	Big Blue Group—Permian
Anson..........	S. 25, 26 & 35, T. 30 S., R. 2 W.	Sumner	April, 1928	1928	4	1,920	359,315,000	305,739,000	665,054,000	Howard lime and Severy shale, Pennsylvanian
Love & Latta...	S. 9, T. 30 S., R. 2 W.	Sumner	October, 1927	1927		2,000	215,600,000	None	477,945,000	Topeka lime, Pennsylvanian

Yocemento Field.—On June 17, 1929, Phillips Petroleum Co. completed its No. 1 Sophus Johnson in the SW. corner NE. ¼ of sec. 9, T. 13 S., R. 19 W., for an initial production of 480 bbl. of oil from 3592 to 3597 ft., and occurring 132 ft. below the top of the Oswald lime. Subsequently the well was deepened to 3684 ft. and penetrated the top of the Pennsylvanian basal conglomerate, 200 ft. below the top of the Oswald lime. No further oil horizons were found and the well was plugged back. A total of four wells have been drilled around the center of sec. 9 and all have been productive. The producing horizon is the 132-ft. pay of the Oswald series of Lansing-Kansas City age. This pay is not present in the Fairport field of Russell County.[2]

McPherson County

McPherson County has been one of the most active areas in western Kansas during the 1928–1929 period. At the close of 1927 there had been developed but one gas field containing three wells. By the end of 1929 there were five gas and oil fields with 37 producing wells.

The wells in the Voshell field are at the present time prorated to 50 bbl. per day. Should this proration plan fail to be continued during 1930, it will be a factor in overproduction.

All of the fields in McPherson County, with the exception of the McPherson field, were defined by core drilling prior to development.

McPherson Gas and Oil Field.—The McPherson field, discovered in September, 1926, is situated in sec. 29, 30, 31 and 32, T. 18 S., R. 2 W. Production is found in a triangular-shaped area, 2 miles wide and 1 mile long. The producing wells are all south of the apex; northward, no wells have been drilled. The oil wells are located on the southwest and southeast flank of the dome and some of them are the lowest wells, structurally, in the field. As developed on top of the Mississippi lime, the McPherson field has in excess of 100 ft. of closure. The top of the Mississippi lime varies in depth from 2855 to 2973 feet.

The gas production occurs in the top of the Mississippi lime. Thirteen gas wells have been completed. The thickness of lime penetrated in the producing wells varies from 22 to 50 ft. The initial production of gas ranges from 4,500,000 to 20,000,000 cu. ft. and averages 10,000,000 cu. ft. The amount of gas is not controlled by the structural position of the well on the dome. The vertical range, structurally, of gas production is 66 ft., and the lowest producing gas well is 106 ft. down the flanks. The immediate apex of the dome is barren of gas and oil, and the highest gas well is 41 ft. structurally lower than the apical well.

The oil production occurs in the top 50 ft. of the Mississippi lime. The oil wells comprise the extreme southwest and southeast producing wells in the field. The vertical range, structurally, of oil production is

[2] L. W. Kesler: *Op. cit.*, 39, Table 7.

70 ft. and the lowest producing oil well is 120 ft. down from the apical well. The initial production varies from 80 to 335 bbl. and in some cases the amount of water produced with the oil is equal to, or exceeds, the oil production.

Voshell Oil Field.—The Voshell field is located in sec. 9 and 10,[3] T. 21 S., R. 3 W. Its discovery was the most important development in western Kansas during 1929. The discovery well, Washabaugh et al. No. 1 Voshell (later purchased by W. C. McBride, Inc.) is located in the NE. corner of sec. 9, T. 21 S., R. 3 W., and was completed in August, 1929, at a total depth of 3304 ft., for an initial production of 40 bbl. The producing horizon, 3301 to 3304 ft., is the Viola limestone. Mechanical difficulties in drilling in this well have prevented it from ever being of much commercial importance. All of the five wells completed by the end of 1929 are situated on the eastern flank of the structure, and at the present time of writing (January, 1930), the field is producing in excess of 100 ft. structurally down the east flank.

The most interesting well so far completed is the structurally highest well, Mid-Kansas Oil & Gas Co. No. 1 Voshell, NE. corner, NW. ¼ NE. ¼ of sec. 9, T. 21 S., R. 3 W. This well produces oil from the Misner sand (3192 to 3224 ft.) and from the Wilcox sand (3374 to 3386 ft., total depth). Viola limestone separates these two horizons. In no other well has the Misner sand been found.

Proration is in force at the present time and the wells are prorated to 50 bbl. per day. The field is now (January, 1930) one-half mile wide and 1 mile in length. No dry holes have been drilled, so the limits of the field are wholly undefined. The principal producing horizon is the Wilcox sand of Ordovician age, but oil is also obtained from the Misner sand (Mississippian) and from the Viola limestone (Ordovician).

Ritz Oil Field.—The Ritz field is located in sec. 1 and 12, T. 20 S., R. 2 W. It is essentially an oil field, although the discovery well yielded gas. This well, McPherson Oil & Gas Co. No. 1 Wedel, center SW. ¼ of sec. 12, T. 20 S., R. 2 W., was completed on Dec. 28, 1928 and encountered 6,500,000 cu. ft. of gas from 2972 to 2983 ft. in the upper part of the Mississippi lime. During 1929 it yielded 195,644,000 cu. ft. of gas.

Subsequently seven oil wells have been brought in. The depth to the top of the Mississippi lime ranges from 2925 to 2960 ft. The oil is produced in the top 51 ft. of the Mississippi lime and the pay zone averages 40 ft. below the top. Gravity of the oil varies from 34 to 38° Bé. The initial production of these wells ranged from 1500 to 35,000 bbl. for the first week. The field is about 2 miles long and one-half mile wide. It is wholly undefined and no dry holes have been drilled.

[3] Wells have been completed in the W. ½ of W. ½ of sec. 10, T. 21 S., R. 3 W., during January, 1930.

Up to the end of 1929 the seven wells produced 315,333 bbl. of oil and 75,320 bbl. of water. This percentage of water is 24 per cent.

Galva Gas Field.—The Galva gas field is located in sec. 11, T. 19 S., R. 2 W. The discovery well, McPherson Oil & Gas Co. No. 1 Decker, center SE. ¼ of sec. 11, T. 19 S., R. 2 W., was completed during July, 1929, for 18,000,000 cu. ft. of gas from 2892 to 2914 ft., 7 ft. below the top of the Mississippi lime. Two additional gas wells have been drilled, of which the largest yielded, initially, 30,000,000 cu. ft. of gas. The limits of the field are undefined.

Grattin Lease.—On Oct. 28, 1929, Slick, Pryor and Lockhart completed their No. 1 Grattin in the NE. corner NW. ¼ NW. ¼ of sec. 34, T. 20 S., R. 3 W., at a total depth of 3108 ft., for an initial production of 256 bbl. of 36° Bé. oil. Production was obtained from 3093 to 3098 ft. in the Mississippi lime, the top of which was penetrated at 3055 ft. The peak production was 350 bbl. on Nov. 9, 1929.

Ness County

The most westerly production of oil in western Kansas was found in October, 1929, by the Continental Oil Co. in its No. 1 Aldrich in the NE. corner SE. ¼ of sec. 17, T. 18 S., R. 25 W. The Oswald series was penetrated at 3855 ft. Production was encountered 573 ft. below the top of the Oswald lime from 4428 to 4430 ft. in a dolomite at the top of the Siliceous lime. The gravity is 33° Bé. During a 6-day official pumping test the well made 910 bbl. of oil and 9 bailers of water. The well was pumped but 4-days in November and 9 days in December and yielded a total, during these two months, of 1660 bbl. of oil, or a daily average of 128 bbl. At the present time the well is being pumped just often enough to remove the water, since it has no pipe line connections.

Rice County

In August, 1929, Slick, Pryor and Lockhart completed their No. 1 Schurr in the NE. corner SW. ¼ of sec. 21, T. 20 S., R. 10 W., at a total depth of 3289 ft. The top of the Oswald series was reached at 3005 ft., and the Pennsylvanian basal conglomerate was penetrated at 3278 ft. The well had an initial production of 240 bbl. of 52° Bé. oil from 3278 to 3284 ft. in the Pennsylvanian basal conglomerate. It produced 11,490 bbl. of oil to the end of 1929. Three offsets and one, quarter-mile location, are being drilled.[4]

Gas was discovered on Jan. 15, 1930, in Boucher Oil Co. No. 1 Boy, in the SW. corner of sec. 16, T. 21 S., R. 10 W. The producing horizon is a sand lense in the Severy shale at a depth of 2550 to 2553 ft. and occurring 65 ft. below the top of the Howard limestone. Its initial

[4] On Feb. 3, 1930, one of these offsets was completed as a producing well in the Siliceous lime.

production is 11,000,000 cu. ft. of gas. The only other well yielding gas from this horizon is the DeForrest Drilling Co. No. 1 Bryan in the SW. corner of sec. 25, T. 30 S., R. 2 W., Sumner County. This well produces gas both from the Howard lime and from a sand zone in the Severy shale.

Russell County

To the close of 1929 Russell County has produced a total of 7,025,211 bbl. of oil from seven fields. In 1928 Russell County maintained its lead as the principal oil-producing county of western Kansas, with a gross yield for the year of 1,273,145 bbl. from 132 wells. During 1929 it dropped to second place despite its production for the year of 1,282,444 bbl. from 156 wells.

Gorham Field.—The Gorham field is located in sec. 32 and 33, T. 13 S., R. 15 W., and sec. 4 and 5, T. 14 S., R. 15 W. Production is obtained in the top 65 ft. of the Oswald series and from a true sand in the Pennsylvanian basal conglomerate. The discovery well of the Pennsylvanian basal conglomerate production, Stearns-Streeter Co. No. 1 Mermis, located in the SW. corner NW. ¼ SW. ¼ of sec. 33, T. 13 S., R. 15 W., was completed in January, 1928, for an initial production of 1000 bbl. of 36° Bé. oil at 3300 ft., 257 ft. below the top of the Oswald lime.

The average depth to the top of the Oswald lime in the Gorham field is 3055 ft. Of the 15 wells producing oil from the Oswald series, 13 wells produce from the 30-ft. pay, 2 wells from the 45-ft. pay, and 1 well from the 65-ft. pay. The wells producing from the Oswald series are scattered throughout sec. 32, T. 13 S., R. 15 W., sec. 5, and the W. ½ of W. ½ of sec. 4, T. 14 S., R. 15 W.

Twelve wells produce from Pennsylvanian basal conglomerate. These are confined to sec. 32 and the W. ½ of W. ½ of sec. 33, T. 13 S., R. 15 W. The average depth to the top of this conglomerate zone is 3317 ft. In the 18 wells which have been drilled to this horizon, the average interval between the top of the Oswald lime and the top of the Pennsylvanian basal conglomerate is 258 ft. Five of these 18 wells have penetrated completely the conglomerate zone. In three of these the Pennsylvanian basal conglomerate was underlain by pre-Cambrian, and in two wells by the Ordovician. In the 12 producing wells of this horizon the amount of penetration is but a few feet.

In the Gorham field the Pennsylvanian basal conglomerate is in contact with either Ordovician or crystalline rocks. It represents an unconformable zone which occupies, at this locality, a stratigraphic position at or near the base of the Kansas City formation.

At the present time the proved area of the Gorham field is 2 miles north and south, and 1 mile east and west. The final productive area

will probably include considerable territory, and will occupy presumably a relatively square area in contrast to the long and narrow shaped area of the Fairport field.

During the 1928–1929 period the Gorham field produced 1,034,265 bbl. of oil. Of this amount, 70 per cent. was produced from the Pennsylvanian basal conglomerate. It is significant that the average production of the Pennsylvanian basal conglomerate wells declined from 580 bbl. per day in February, 1928, to 57 bbl. per day in December, 1929.

The average recovery per acre to the close of 1929, and the average daily production during December, 1929, are shown below:

Producing Horizon	Number of Producing Wells	Per Acre Recovery to Close of 1929, Bbl.	Proven Acreage	Daily Average Production, December, 1929, Bbl.
Pennsylvanian basal conglomerate.....	12	6000	120	57
Oswald series........................	15	2620	150	34
Gorham field average................	27	4100	270	44

South Fairport Field.—In a previous publication[5] this was called the Austin field. Since that time it has received officially the name South Fairport field and the term Austin should be dropped.

The South Fairport field is situated in the W. ½ of sec. 30 and 31, T. ½ S., R. 15 W., the SE. ¼ SE. ¼ of sec. 25 and the E. ½ of sec. 36, T. 12 S., R. 16 W., the NW. ¼ of sec. 6, T. 13 S., R. 15 W., and the NE. ¼ of sec. 1, T. 13 S., R. 16 W. The field is one-half mile wide and 2 miles long. It is located on the same line of folding as the Fairport field and separated therefrom by a structural saddle.

The average depth to the top of the Oswald lime is 3030 ft. Production is from four pays in the Oswald series. Of the 21 producing wells, 19 wells produce from the Oswald pay, 12 wells from the 30-ft. pay, 1 well from the 45-ft. pay, and 2 wells from the 220-ft. pay.

Four wells have penetrated into either the Pennsylvanian basal Conglomerate or the underlying Ordovician without finding production in the conglomerate zone. Two of these wells are located in the field and were plugged back to produce from the Oswald series, and two are dry holes situated immediately to the southwest.

North Fairport Field.—Four wells have been drilled along the axis of the Fairport Anticline from 1 to 3 miles northeast of the most northern well in the Fairport field. A distance of 2 miles separates two of these

[5] L. W. Kesler: *Op. cit.*, 40.

wells, a third well lies halfway between, and the fourth well offsets to the north the southernmost well. These four wells comprise the present, and wholly undeveloped, North Fairport field. Its width is as yet but one location. It is situated in sec. 9, 20 and 29, T. 11 S., R. 15 W., and production was first discovered on June 14, 1928.

The producing horizon of these four wells is from three pays in the Oswald series. One well is producing from the 30-ft. pay, two wells from the 190-ft. pay, and two wells from the 220-ft. pay. The 190-ft. pay is not present in the Fairport field.

Susank Field.—The discovery well of this field, T. B. Slick No. 1 Sellens, located in the SW. corner NE. ¼ of sec. 36, T. 15 S., R. 13 W., was completed on June 20, 1929, at a depth of 3352 ft. in the Pennsylvanian basal conglomerate. Since the well made about 50 per cent. oil and 50 per cent. water it was deepened. Pipe was set on top of the Siliceous lime and all oil and water shut off. It was then drilled into the Siliceous lime to a total depth of 3365 ft. and came in for an initial production of an excess of 500 bbl. and no water. By the close of 1929 two additional producing wells, offsetting the discovery, had been completed. Both of these have penetrated into the Siliceous lime and derive their production approximately half from the Pennsylvanian basal conglomerate and half from the Siliceous lime.

The limits of the Susank field are wholly undefined. When developed it will be similar presumably to the Gorham field. In six months it has produced 27,910 bbl. of oil from three wells. The second well was not completed until Oct. 25, 1929. A detailed record of the production from this field follows:

Well	Location	Production from Pennsylvanian Basal Conglomerate, Bbl.	Production from Siliceous Lime, Bbl.	Total Production, Bbl.
Prairie No. 1 Sellens	SW. NE. S. 36	....	8,925	8,925
Slick No. 1 Sellens	NW. SE. S. 36	5,824*	5,824*	11,648
Prairie & Slick No. 1 Sellens.	NE. SW. S. 36	3,668*	3,669*	7,337
		9,492	18,418	27,910

* Approximate.

Ochs Lease.—On Oct. 14, 1929, the Empire Oil & Refining Co. completed its No. 1 Ochs, located in the SE. corners NE. ¼ NE. ¼ of sec. 23, T. 15 S., R. 14 W., at a total depth of 3369 ft. It had an initial production of 232 bbl. of 36° Bé. oil. Production is obtained from 3364

to 3369 ft., near the top of the Pennsylvanian basal conglomerate and 254 ft. below the top of the Oswald lime. To date, no additional wells have been completed and as yet the field has no official name.

Sedgwick County

The most important discovery of oil in western Kansas during the latter part of 1928 was in Sedgwick County. Prior to this time 35 tests had been drilled in the county. None of these were productive, although showings of oil and gas were reported from a number of wells.

On Aug. 21, 1928 the Bu-vi-bar Oil, Continental and Gypsy Oil companies completed their No. 1 Wright in sec. 12, T. 26 S., R. 1 W., for an initial production of 1700 bbl. of oil from the Simpson dolomite. This discovery lead immediately to an active drilling campaign. Its success is evidenced by the fact that in 16 months (Aug. 21, 1928, to Dec. 31, 1929) four major oil fields had been discovered with an additional eight areas of production each represented by a single producing well. The total recovery of oil from the 167 producing wells in Sedgwick County has been 9,139,208 bbl. distributed as shown in Table 6. It is significant that in 1929 Sedgwick County produced 21.8 per cent. of all the oil recovered in Kansas for the year, and ranked second in county production. Were it not for the fact that production is prorated in the Valley Center and Greenwich fields, this county would have ranked first in production during 1929.

TABLE 6.—*Cumulative Production in Sedgwick County from August, 1928, to Dec. 31, 1929*

Field	Location	Date of Discovery	Production, Bbl.	Number of Wells	Per Acre Recovery, Bbl.	Number of Acres Producing	Producing Horizon
Valley Center	T. 26 S., R. 1 W. T. 26 S., R. 1 E.	Aug. 21, 1928	7,407,443	111	8,230	900	Chiefly Simpson dolomite
Goodrich.....	T. 25 S., R. 1 E.	Dec. 4, 1928	440,390	4	11,000	40	Mississippi lime Simpson dolomite
Robbins......	T. 28 S., R. 1 E.	April 15, 1929	158,221	8	1,975	80	Mississippi lime
Greenwich....	T. 26 S., R. 2 E.	April 27, 1929	1,046,431	36	5,235	200	Simpson dolomite Mississippi lime
Miscellaneous.			86,723	8		80	
Total......			9,139,208	167		1,300	

Oil in Sedgwick County is produced from six horizons. The gross amount of oil recovered from each horizon, together with the number of wells producing therefrom, is as follows:

Producing Horizon	Gross Production to Dec. 31, 1929, Bbl.	Number of Wells Producing Dec. 31, 1929
Simpson dolomite (Ordovician)	7,645,091	122
Mississippi lime (Mississippian)	1,389,964	40
Misner sand (Mississippian)	50,711	1
Basal sand (Pennsylvanian)	47,095	2
Wilcox sand (Ordovician)	3,000	1
Kansas City formation (Pennsylvanian)	2,347	1
Totals	9,139,208	167

It is of unusual interest to observe the amount of water produced with the oil in the three principal Mississippi lime fields in Sedgwick County.

Field	Gross Production of Oil from Mississippi Lime, Bbl.	Gross Production of Water in Addition to Oil, Bbl.	Water, Per Cent.
Greenwich	769,460	945,665	123
Goodrich	436,033	310,000*	70
Robbins	158,221	7,965	5

* Approximate.

Valley Center Field.—The Valley Center field is situated in sec. 36, T. 25 S., R. 1 W., sec. 1 and 12, T. 26 S., R. 1 W., and sec. 6 and 7, T. 26 S., R. 1 E. The field has a length of 2¼ miles north and south and a width of 14 locations east and west. At the present time it is limited only to the north by 9 dry holes in the Valley Center town site and to the southeast by one well in the NE. corner of sec. 18, T. 26 S., R. 1 W.

By the close of 1929 a total of 124 wells had been completed in the Valley Center field. The principal producing horizon is from two dolomite pays in the upper part of the Simpson formation of Ordovician age, and called locally the First and Second Simpson dolomites. An analysis of these 124 completions follows:

Number of wells producing from Second Simpson dolomite	96
Number of wells producing from First Simpson dolomite	13
Number of wells producing from Misner sand (Mississippian)	1
Number of dry holes	14
Total	124

The average depth to the Second Simpson dolomite is 3375 ft. In those wells which have been completed in the First Simpson dolomite

the amount of penetration varies from 2 to 13 ft. and averages 8 ft. For the Second Simpson dolomite the amount of penetration varies from 2 to 15 ft. and averages 7 feet.

Six tests in the Valley Center field have been deepened to the Siliceous lime. Five of these penetrated into this horizon for a distance varying from 12 to 120 ft. One test, however, Cosden Oil Co. No. 1 DeWees, in sec. 1, T. 26 S., R. 1 W., was abandoned early in January, 1930, at a depth of 4006 ft., 540 ft. below the top of the Siliceous lime.

Greenwich Field.—The Greenwich field is the second most important oil pool in Sedgwick County. It was discovered on April 27, 1929, by the Shell Petroleum Corpn. at its No. 1 Lygrisse, located in the SE, corner NE. ¼ of sec. 15, T. 26 S., R. 2 E., and was completed for an initial production of 2118 bbl. from 3164 to 3170 ft. Its producing horizon is a dolomite in the top of the Simpson formation. The discovery well made no water until June 23, 1929. Thereafter it made 5 bbl. of water per day until Oct. 13. Between then and the end of 1929 no water has appeared with the oil.

Additional interest in this field developed on June 22, 1929, when production was encountered in the top of the Mississippi lime by the Shell Petroleum Corpn. No. 1 Community, situated in Lot 17, Block 7 of the Greenwich town site in the SE. ¼ SW. ¼ of sec. 15, T. 26 S., R. 2 E. This well had an initial production of 1555 bbl. of 43° Bé. oil from 2922 to 2924 feet.

The Greenwich field is located principally in sec. 14 and 15, T. 26 S., R. 2 E. However, there is one producing well in the SE. corner of sec. 10, one in the SW. corner of sec. 11, and one in the N. ½ NE. ¼ of sec. 22, all in T. 26 S., R. 2 E. The wells producing from the Simpson formation are located, chiefly along the west line of sec. 14 and the east line of sec. 15. The Mississippi lime wells are situated in and around the Greenwich town site in the S. ½ of sec. 15, and around the common corner of sec. 10, 11, 14 and 15. The Greenwich town site, with an area of 40 acres, has 15 Mississippi lime wells, one Simpson well, and five dry holes.

The number of tests completed in the Greenwich field totals 53. Of this number 27 wells are producing from the Mississippi lime, 11 wells are producing from the Simpson formation, 3 wells have been abandoned in the Mississippi lime, 11 wells have been abandoned in the Simpson formation or below, and 1 well was abandoned above the Mississippi lime. The average depth to the top of the Mississippi lime is 2908 ft. and to the top of the Simpson dolomite 3210 feet.

The most interesting factor relative to the Greenwich field is that it has produced 1,046,431 bbl. of oil and 1,014,993 bbl. of water, or only 31,438 more barrels of oil than water. The Mississippi lime wells produce 123 per cent. more barrels of water than oil. In the Simpson wells the yield of water is 25 per cent. in addition to the oil produced.

One of the wells of greatest interest in this field is Shell Petroleum Corpn. No. 2 Borg in the NW. corner SW. ¼ SW. ¼ of sec. 14, T. 26 S., R. 2 E., completed in December, 1929. This well penetrated Simpson dolomite from 3229 to 3280 ft., in which a hole full of water was encountered. At 3280 ft. it reached the Wilcox sand series and had another hole full of water in the top of this horizon. Commercial production was found from 3350 to 3354 ft. in Wilcox sand, 121 ft. below the top of the Simpson formation, 70 ft. below the top of the Wilcox sand series, and about 50 ft. above the top of the Siliceous lime. No. 2 Borg is the only well in Sedgwick County producing from the Wilcox sand and to our knowledge is the only well in Kansas that produces from a horizon as far below the top of the Wilcox. During December, 1929, it produced 3000 bbl. of oil and no water.

To Dec. 31, 1929, the per acre recovery from the wells producing from the Mississippi lime has been 8550 bbl. as compared with 2520 bbl. of oil per acre for those wells producing from the Simpson formation. The average recovery for the entire field has been 5235 bbl. of oil per acre.

Goodrich Field.—The second field to be discovered in Sedgwick County, and the third in importance, is the Goodrich field located in sec. 16, T. 25 S., R. 1 E. The discovery well, Continental Oil Co. No. 1 Goodrich, SW. corner NE. ¼ SW. ¼ of sec. 16. T. 25 S., R. 1 E., was brought in on Dec. 4, 1928, for an initial production of 4139 bbl. of 42.5° Bé. oil from 3014 to 3024 ft. According to the Continental Oil Co. the most authentic samples of the producing horizon were composed almost wholly of chert, and the age of the production has since been established definitely as the top of the Mississippi lime.

Two additional Mississippi lime wells have been completed in sec. 16. These three wells have together produced 436,033 bbl. of oil.

The south offset of the discovery well, No. 1 Westerfield, NW. corner SE. ¼ SW. ¼ of sec. 16, T. 25 S., R. 1 E., failed to obtain production in the Mississippi lime and was deepened to the Siliceous lime and completed at a total depth of 3511 ft. The top of the Simpson formation was reached at 3326 ft. After completion the well was plugged back to 3331 to 3332 ft. and had an initial production of 125 bbl. of 39° Bé. oil from a dolomite in the top of the Simpson formation. Completed in April, 1929, it produced 1865 bbl. that month, dropped to 107 bbl. for the month of May, and during December, 1929, yielded 506 bbl. of oil. Its gross production has been 4357 bbl. of oil and approximately 48,800 bbl. of water in 9 months.

Robbins Field.—The Robbins field is situated in sec. 20 and 21, R. 28 S., R. 1 E. It was discovered on April 15, 1929, by Shell Petroleum Corpn. No. 1 Robbins in the NW. corner SW. ¼ of sec. 21, T. 28 S., R. 1 E., and completed for an initial production of 218 bbl. of 41° Bé.

TABLE 7.—*Producing Wells Completed in Sedgwick County during 1929*

Name	Location	Total Depth, Ft.	Top Mississippi Lime, Ft.	Depth of Producing Horizon, Ft.	Initial Production, Bbl.	Gravity, Deg. Bé.	Producing Horizon	Cumulative Production, 1929, Bbl.
Connell Petroleum Co. No. 1 Cross	27-25 S., 1 W.	3,650	3,190	2,690 to 2,730	20	35	Middle Kansas City formation (Pennsylvanian)	2,347
Producers & Refiners No. 1 Kuske	24-25 S., 1 E.	3,017	Not Reached	3,013 to 3,017	1,800	43	Basal sand (Pennsylvanian)	30,689
Barnsdall Oil Co.* No. 1 Samuels	24-25 S., 1 E.	3,662	3,064	3,064 to 3,067	140	40	Mississippi lime	8,426 (Abandoned)
Mars Oil Co.† No. 1 Miller	2-26 S., 2 E.	2,894	2,857	2,893 to 2,894	460	45	Mississippi lime	5,934
Patton and Wentz No. 1 Swanson	6-26 S., 2 E.	3,010	Not Reached	3,001 to 3,010	197	38	Basal sand (Pennsylvanian)	16,406
Plains Oil Co.‡ No. 1 Curry	2-27 S., 1 W.	3,401	3,078	3,389 to 3,391	170	41	Simpson dolomite (Ordovician)	11,031
Fisher and Lauck No. 1 Trustee	19-27 S., 2 E.	2,938	2,927	2,937 to 2,938	122	44	Mississippi lime	2,933
E. W. Marland Co., Inc. No. 1 Mackey	30-27 S., 2 E.	2,970	2,955	2,958 to 2,970	67	41	Mississippi lime	8,957

* Plugged and abandoned in June, 1929.
† Produced 5934 bbl. oil and 74,353 bbl. water from August to December, 1929.
‡ The most important discovery in the above table; large potential acreage for field.

oil from 3092 to 3102 ft. This well reached a peak production of 775 bbl. on May 11, 1929, and produced no water until June 23. At the present time the field has 8 producing wells, and 2 dry holes. It has a length of 4 locations north and south, and 2 locations east and west. The producing horizon is the top of the Mississippi lime, found at an average depth of 3090 feet.

A point of unusual interest is the small amount of water (5 per cent.) produced with the oil, in contrast to the reverse condition in the Greenwich field.

Miscellaneous Production.—There are eight additional areas of commercial production in Sedgwick County, each represented by a single producing well. Information on these wells appears in Table 7.

Trego County

Oil was first discovered in Trego County on May 19, 1929, by Central Commercial Oil Co. in its No. 1 Ellis King, in the NE. corner SW. ¼ NE. ¼ of sec. 20, T. 13 S., R. 21 W., in the extreme east-central part of the county. The producing area has been officially named the Rega field. The production, at 3960 to 3972 ft., was found in the top of the Pennsylvanian basal conglomerate, 294 ft. below the top of the Oswald series, which was reached at 3666 ft. The initial production was 290 bbl. of oil. No offsets have been started to the discovery well.

Prior to the discovery of oil in the Rega field but three wells had been drilled for oil in Trego County. One of these was completed in the Permian, another in the middle Pennsylvanian, and the third in the Ordovician. Subsequent to this discovery one test had been drilled, without success, to the pre-Cambrian on the same line of folding, while two others are drilling at interesting depths. On other lines of folding in Trego County two additional wells have been abandoned recently in the Pennsylvanian basal conglomerate with only small shows of oil in this horizon.

Core Drills and Geophysical Operations

Core drills have been operated in Kansas by practically all of the major oil and gas companies during the last four years. At the present time, January, 1930, there are 50 drills in operation.

The greatest activity is in the central western part of the state and numerous pools have been discovered as a direct result of core hole information. Included in the list are the Valley Center pool opened in sec. 6 and 7, T. 26, R. 1 E.; the Goodrich pool in sec. 16, T. 25, R. 1 E.; the Lygrisse pool opened in sec. 15, T. 25, R. 1 E.; the Curry pool in T. 27, R. 1 W. and the Robbins pool in T. 28, R. 1 E., all in Sedgwick County; and the Caldwell pool in T. 35, R. 3 W. and the Peasel well in sec. 33, T. 31, R, 1 W. in Sumner County.

Several gas fields and two oil pools that give promise of very large production, the Voshel pool in T. 21, R. 3 W. and the Ritz pool in T. 20, R. 2 W., in McPherson County, have been discovered on favorable structure worked out by use of the core drills.

In western Kansas the Sellens pool, sec. 26, T. 15, R. 13, W., the Ochs pool in sec. 23, T. 15, R. 14 W. and a north extension of the old Fairport pool in T. 11, R. 15 W., all in Russell County were discovered as a result of core drill information. Several other pools in Ellis County are included in the list.

A small number of torsion balances and seismographs have been in use particularly in the western counties, Barton, Pawnee, and Edwards. Many magnetometers have been in use but in recent months have given way to the more expensive but more reliable information obtained by core drilling. A considerable number of areas in Western Kansas have been worked over by field parties using magnetometers and their findings later checked by core drilling.

Very little geophysical work has been done in the eastern part of the state.

Acknowledgments

Figures on production and completion have been brought up to date from a previous review prepared by L. W. Kesler for 1927, by the use of information taken from and contributed by the *Oil and Gas Journal*.

The review of development for Eastern Kansas is a compilation resulting from a combination of information contributed by Anthony Folger, Gypsy Oil Co., for the year 1928, who acknowledges contribution from J. R. Reeves, Empire Oil & Refining Co.; J. S. Barwick, Skelly Oil Co.; Homer Charles, Oklahoma Natural Gas Corpn.; R. B. Rutledge, Barnsdall Oil Corpn.; B. S. Ridgeway, Roth and Faurot; and J. L. Garlough, Consulting Geologist; and of information for 1929, contributed partly by R. L. Kidd, Empire Oil & Refining Co.; John L. Rich, Wm. L. Stryker, Lee and Garlough, Wm. Ainsworth, consulting geologists.

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Petroleum Developments in Oklahoma during 1929

By H. B. Goodrich,* Tulsa, Okla.

(New York Meeting, February, 1930)

In considering historically oil development in Oklahoma, it must be recognized that basic evolutionary factors interlock and have an effect in common throughout the whole oil industry, regardless of locality or minor problems. Oklahoma, as the third in rank of oil-producing states (Texas being first and California second in production for 1929) has, like the rest, advanced to at least a partial recognition of the words, "Conservation," "Unitization," "Curtailment," "Proration," and especially "Cooperation."

Whether through altruism (of which there have been examples) or by exercise of good business common sense, Oklahoma operators realize that the oil business can run itself by cooperative action for the good of all. In this long-continued period of overproduction, Oklahoma has brought the advancing output down to limit of market requirements at least temporarily.

Sources of Statistical Data

For this paper, figures published by four recognized authorities were consulted. Between themselves these vary only a negligible per cent. in their totals. To be consistent, and on account of earlier availability the estimates published by the *Oil and Gas Journal* are mainly used herein, supplemented from other public and private sources.

General Oil Production in Oklahoma

In 1927 Oklahoma's peak of all years was 276,022,024 barrels.
In 1928 Oklahoma's total production was 247,500,851 barrels.
In 1929 Oklahoma's total production was 252,229,474 barrels.

The efforts of proration and curtailment programs on flush and semi-flush districts such as Greater Seminole, Oklahoma City, Logan County and others, with the natural decline of older pools, kept 1929 below 1927, but still the total was greater than in 1928.

The total United States production for 1929 is herein taken as estimated at 1,004,266,723 bbl.† Oklahoma produced 25.1 per cent. of

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† Since this was written, U. S. Bureau of Mines figures are reported: Total U. S. production, 1,005,598,000 bbl.; Oklahoma production, 253,704,000 bbl. Oklahoma's production was approximately 25 per cent. of the total.

that total. The daily average production for Oklahoma for 1929 was 691,040 bbl., as against 2,751,416 bbl. for the United States. The grand total of oil produced in Oklahoma is 2,804,000,000 bbl. On this estimate the Oklahoma 1929 production was 9 per cent. of the grand total.

General Oil Well Developments

Table 1 shows development yearly from 1927 to 1929. Probably a total of 99,300 producers have been drilled in Oklahoma, of which 63,500 were producing in 1929; or an average of 10.9 bbl. per well per day, about the same rate as the preceding 12 months.

Table 1.—*Oklahoma Well Development*

Years	Completions	Initial Production, Bbl.	Oil Wells	Dry Holes	Gas Wells	Average Production per Well, Bbl.	Percentage of Oil Producers
1929	3,613	1,178,945	1,999	1,245	369	585	55
1928	3,679	1,016,000	1,961	1,227	491	518	53
1927	4,513	1,971,081	2,562	1,443	508	769	57

General Conditions through the Year

Due to an active determination of operators to bring the daily average down to 650,000 bbl. Oklahoma dropped, early in 1929, from first to third place among oil-producing states. Late in January, when the daily average was 726,000 bbl., the price of crude was cut. Seminole was prorated to meet the 650,000-bbl. daily average and nine major companies effected a Sunday shutdown. On March 20, the daily average for the week was 644,000 bbl. In May the daily average was increased to 725,000 bbl. by the Oklahoma Coporation Commission and the price of crude in Oklahoma was raised. In late June and early July, oil was withdrawn from storage at about 45,000 bbl. per day. Market conditions soon reversed, however, and the daily average reached 729,000 bbl. Oklahoma City became of major importance. Greater Seminole showed a decline, which, however, was not maintained throughout August. The year's maximum daily average was 747,895 bbl. in the week ending Sept. 14. A 30-day shutdown was ordered and it was followed by an order applying curtailment to all flush areas. Due to the curtailment program, in the week ending Nov. 9, Oklahoma's daily average dropped to 617,000 bbl., when potential production was more than 800,000 bbl. daily. On Dec. 23, 1929, proration of all flush pools was extended through the first quarter of 1930.

Despite overproduction, oil leasing has been active on a large scale, attention being directed to the region between Oklahoma City pool and

Seminole fields. During the fall geophysical and geological surveys were made in many of the northern and western counties.

Notwithstanding the expense of deep tests (the average cost of an Oklahoma City well is perhaps $155,000) the success of wells more than 6000 ft. deep in Logan County and Oklahoma City encouraged deep testing in the state. There are many examples. The deepest hole in Oklahoma is the I. T. I. O. Cook No. 1, sec. 10, N. 11 E., Coal County, abandoned dry at 7890 ft., on Aug. 30, 1929. The deepest unfinished well is P. O. & G. Slick & Phillips No. 1 Sudik, sec. 8, 10 N., 2 W., Cleveland County, total depth at last report 7720 ft.; sand with water 7690 to 7720 ft., and plugging back to test shallower show. The deepest actual production in the state is the Healdton Oil & Gas Co. No. 2 Gragg, S. W. S. W. sec. 18 N.-4 W., Logan County, which was completed in September or October, depth 6620 ft.; initial production, 115 barrels.

Important Oil Well Developments

Aside from the older pools which showed natural declines, the flush pools on which attention was centered at the end of 1928 were: (1) Greater Seminole; (2) Allen pool; (3) Logan County, Crescent-Lovell, and Marshall pool; (4) Oklahoma City pool.

Greater Seminole

This district more properly includes the following pools: Earlsboro and East Earlsboro, Little River, Searight, Seminole, Bowlegs, Maud, Mission, Carr City, all of Seminole County, except Maud in Pottawatomie County. To conform with the grouping in Petroleum Development and Technology 1928–29 (A. I. M. E.), page 388, St. Louis, East St. Louis and Pearson Switch, in Pottawatomie and Seminole counties are here included although most production records carry these last in another group. The estimated production of these is as follows: 1926, 10,917,225 bbl.; 1927, 136,104,000 bbl.; 1928, 127,656,000 bbl.; 1929, 126,175,994 bbl.; grand total, 400,853,169 barrels.

There were, as of Dec. 31, 1929, approximately 2291 producing wells in this district. Following are some of the outstanding events: Earlsboro with East Earlsboro is the largest pool of the group. It is credited with a grand total production of about 95,000,000 bbl. East Earlsboro which has produced 6,800,000 bbl. was discovered by the Magnolia Moore 1 in sec. 24, 9 N.-5 E., June, 1929, in the Wilcox sand at 4210–4229 ft. There are 98 producing and 60 drilling wells in East Earlsboro.

East Little River extension discovery well was the Mid-Continent Petroleum Corpn. No. 1 Smith N.E. corner sec. 5-7 N. 7 E. opening up the Wilcox at 4427–40 feet.

The notable accomplishment is the development of the Cromwell or Gilcrease sand in this district during the year. What really led to

this was the Magnolia Reed well in sec. 31-8 N.7 E., which had a large gas well with some oil at 3200 ft. in August, 1927. Later, with the discovery of the Wilcox, this well was deepened. Other wells found the shallower showings, but passed them up. However, later, several wells came back from the Wilcox, ripped the casing and produced from the shallower sand. This producing horizon no doubt, holds great oil reserves for the future. The largest producer is the Mid-Continent Smith 13, completed Nov. 9, 1929, in sec. 5-7 N. 7 E., sand 3190–3207 ft., initial production 2310 bbl. It was shut in for proration.

The Little River pool produced 29,000,000 bbl. in 1929. There are 400 producing wells.

On the north side of St. Louis pool, Irwin and Martin Kelly 1, an extension discovery of the Hunton, was at 3775 ft. early in May, 1929. This, together with discovery in the Asher district near by, caused activity of development. In the entire St. Louis pool there are now 452 wells with a daily average of 47,643 bbl. The pool has produced a total of about 51,000,000 barrels.

Carr City Pool

The discovery of the Wilcox sand in sec. 14-8 N.-5 E. was noted in December, 1928. This pool was carried in reports under Maud, but in the last of March, 1929, it was separately carried. The Maud pool included Misener and Hunton lime production in Pottawatomie County, while Carr City is Wilcox sand production in Seminole County. There are 57 wells, daily average 7808 bbl. The total production, all in 1929, has been about 2,000,000 barrels.

The potential production of Greater Seminole is estimated at 350,000 barrels.

Allen Pool

The Allen pool in Pontotoc County had shallower development dating back as far as 1913, but the Wilcox sand discovery was made by the Sinclair Oil & Gas Co. in September, 1928, in sec. 7-5 N. 8 E. All the development was in 1929 and there are 238 producing wells averaging daily production of 21,315 bbl. The pool has produced about 9,000,000 barrels.

Logan County

Logan County has two pools. The Crescent or Lovell pool in Township 18 N. R. 4 W., although previously known in the shallower sands, was probably discovered by the T. P. Coal & Oil Co. well in sec. 27-18 N.-4 W. in the Wilcox at 6295–6389 ft., in January, 1928, although that well did not produce.

This pool is of less importance than the Marshall or Roxana pool. It has 19 wells, partly in the Wilcox, but mostly gas wells in the Tonkawa sand. However, it has the distinction of the deepest producing well in the state, brought in about September, 1929.

The Marshall or Roxana pool discovery was the McCully No. 1 sec. 30-19-4 W., June 28, 1927, Wilcox sand 5983–6086 ft., initial production 2800 bbl. of 41–42° gravity. Development has been mainly in 1929, but the Shell company's policy has been along conservation lines to average its production to about 16,000 bbl. The discovery well is said to have made total production of 1,500,000 bbl. There has been considerable activity and the pool has been extended, notably by the Cosden well in sec. 31-19-4 W. early in December. This pool is recognized as a major pool and is now prorated 20 per cent. There are 43 producing wells and estimated production for 1929 is 5,646,800 barrels.

Oklahoma City Pool

From all points of view, the purely scientific, the working technique of very deep drilling and production, and its effects on economics of the oil industry, the Oklahoma City pool has been the most interesting of fields. The discovery well was located on geological advice as a wildcat in sec. 24-11 N. 3 W., 50 miles from production. It was completed Dec. 4, 1928, at about 6500 ft. and has produced a total of 1,004,000 bbl. Because of the very deep drilling, the second well, Sinclair, Stamper No. 1 sec. 30-11 N. 2 W., was not completed until June 20. The largest well was Fuzzell No. 1 in sec. 13-11 N. 3 W. rated at 43,557 bbl. During the development two wells blew in making large quantities of gasoline—the Kinter No. 1 sec. 30-11 N. 2 W. and Watters No. 1 sec. 25-11 N. 3 W.

At the present time, there are 160 operations; 68 wells have been completed. The potential production is more than 400,000 bbl. daily with a pipe line capacity of 166,000 bbl., but the field is prorated as described above. The total produced by the field since discovery is 8,818,000 barrels.

The area which has perhaps been defined at the SE. and SW. only by dry holes is now estimated at about 5000 acres which is likely to be extended by drilling operations now in process. Originally well-spacing was at 40 acres per well, but smaller holdings have made 10 acres per well common practice.

Subsurface geology is becoming better realized. Many new facts have been added to geological knowledge by the Oklahoma City field. Generally the oil horizons are found in the Arbuckle Lime which has been penetrated more than 400 ft., and in the "Detrital Horizon." The former has produced much greater quantity than the latter and has more than 50 wells producing from it, but on the other hand, the Lime horizon wells show considerable water, and greater decrease in gas pressure. The Detrital Horizon wells have no present water menace and longer life is probable. As to the Detrital Horizon, it is said that from data on the Tidal Slick well in sec. 13-13 N. 1 W., geologists have arrived at some interesting correlation conclusions, changing former ideas.

New Discoveries of the Major Class

All the above include what are truly discoveries of 1929, either geographical extensions of, or vertical additions to, pools already known. The following, in the order of apparent importance, are new discoveries which may be recognized as major pools now or lead to some values in the future.

Sasakwa Pool

This pool is in T. 6 N. R. 7 and 8 E. in Seminole and Hughes counties. The discovery well was the Sinclair-Davis 1 in sec. 7-6 N.-8 E. completed June 12, 1929. It had been originally drilled 2 ft. into the Wilcox at 4201 ft., but was plugged back to the Simpson sand with initial production of 1027 bbl. from it at 4085–4164 ft. At present there are 40 wells, averaging 12,000 bbl. daily. Total production has been 1,600,000 barrels.

Asher Pool

The Asher pool is in T. 6 N. R. 4 E. Pottawatomie County. Discovery well was Simms Lester 1 SE. cor. NE. NE. sec. 19-6 N.-4 E. completed in the Viola at 3699 ft. on April 10. In the first seven days' test, output increased up to 2700 bbl. daily. A month later, an offset came in at 3597–3662 ft. with initial production of 3000 bbl. Then 35 wells were started to this shallower horizon, but the pool soon began to decline. There are now 26 producing wells, daily average production 9851 bbl. The pool has produced about 1,500,000 bbl. from June 30 to Dec. 31, 1929.

Konawa Pool

The Konawa pool, located in T. 6 N. 6 E. Seminole County is about the latest discovery to be classed among major pools. The E. L. Harris, Wilcox and Doppleman Drilling Co. discovery Harjoche 1 in SE. NE. SE. sec. 8-6 N. 6 E. had the Wilcox sand with sulfur water at 4065 ft. on Oct. 21. The hole was plugged back and tested at the Cromwell (?) at 2950 ft. It had oil and water; was further plugged and developed at 2860–65 ft. On Nov. 5, 1929, it was completed for a 400-bbl. well, initial production, and is now doing probably 200 bbl. Two offset wells came in about Christmas time for 1000–1600 bbl. initial. There is very great interest, for the relation to other production suggests a sizable prospective area. At the present time, there are three producing oil wells and one gas well, and average daily production is 3087 bbl. There are 40 drilling operations.

Beebe Pool

A discovery in the Viola limestone at the old Beebe pool of Pontotoc County was recorded by the American Oil & Refining Co. in sec. 19-5 N.-5 E. in April at about 2300 ft. At the present time, there are 58 wells. Wells came in as high as 1000 bbl. Daily average is said to be 3000 barrels.

Pool Northeast of Perry

In the old Otoe Reservation, Peerless Oil and others drilled Wentz No. 1 in SW. of sec. 22-22 N.-1 E. and on Dec. 15, 1929, discovered oil in the Layton sand at 3282 ft. On Dec. 23 it was deepened to a total depth of 3300 ft. and flowed. It has been reported as a 200-bbl. well. It is not completed at this writing, but apparently offers good prospects for future development. In connection with this discovery, should be mentioned a deeper discovery in the old Bu Vi Bar pool, west of Perry in Noble County, the Magnolia Young 1 sec. 22-21 N.-2 W. of the Misener sand at 5100–5104 ft., reported on Dec. 12 as a possible 300-bbl. well.

West Chandler

The discovery well was Magnolia Decker No. 1 in SE. SW. SE. 8-14 N.-4 E., Lincoln County, completed July 28 with Simpson 4953–4972 ft. Initial production was said to be 80 bbl. per hr. which declined rapidly. There are now three producers; seven wells are drilling.

Palacine Area

The discovery well was the Wirt Franklin Spain No. 1 SW. SE. NW. sec. 9-2 S.-6 W. in Stephens County, completed July 18, 1929; deepest sand was 3226–3228 ft. However, probably no correlation has been made and the sand is really a conglomerate or "detrital" zone ranging from 2950–3200 ft. depth. The initial production was 682 bbl., but no estimate of the future has been made. In the area there is now a second well, which was reported as high as 800 bbl. initial production. Several wells are being drilled near the discovery, one of which has perhaps entered the Arbuckle lime.

Also in Stephens County is an interesting group of four wells in SE. sec. 21-2 S.-7 W. of George Pace et al; discovery date, July 23. Possibly this connects the Comanche and Palacine pools but in a different sand at 1734–36 ft. The initial production was 240 bbl. per day.

Payne County

Near the town of Cushing in sec. 4-18 N.-5 E., Shaffer company in Little Chief No. 2 made discovery of oil in the Wilcox sand at 3482–3534 ft. on Sept. 28, 1929. The first well on this lease had been a gas well in shallow sand. The discovery's initial production was about 900 bbl. Eight wells have been drilled and six are now drilling. The pool was limited to the south by a dry hole in sec. 4-18 N.-5 E.

State Line Pool

The original discovery was in Kansas, the Gypsy Williams 1 on May 10. The pool was extended on to the Oklahoma side of the line by an Amerada offset in sec. 17-29 N.-9 W. Wilcox sand at 4781–85 ft. Initial

production was 500 bbl. but the area was cut off by a Gypsy dry hole. On Oct. 9, the State Line pool gaged 1851 bbl. from four wells.

McClain County

The Homaokla Newsom 1 in NE of sec. 16-5 N.-3 E., a wildcat well on Dec. 6, found the Viola at 3087–3605 ft. Originally reported as about a 200-bbl. well, it is considerably smaller but its value is in opening up possibilities in new territory for further drilling tests, in advance of the known fields, such as Beebe. This discovery is the first in McClain County.

Miscellaneous Developments

There are some findings which may not add much to immediate oil recoveries, but should be mentioned because they suggest previously unrecognized oil reserves.

In Cotton County, in SE. cor. of T.-1 S.-10 W. and NE. of 2S.-10 W. is an east side extension of the Walters field. This was discovered in March with sand at 2166–2177 ft. of 35° gravity oil. Production is from 30 to 200 bbl. per well.

Further development of the shallow oil in Marshall County on the Preston Anticline, with wells ranging up to 100 bbl. at less than 600 ft. depth has attracted attention also.

There is also a small development of shallow oil near Vinita in Craig County which has not yet found a market.

Conclusion

From all the above it appears that while the oil producers' main attention during 1929 was toward curtailing an overproduction down to the market demand, and seemed to be successful in the last two months, still there were constructive drilling developments, leading to the future. The novel problems arising from the discoveries in the major pools, have caused a startling advance along all lines of petroleum engineering. Petroleum technology and geology have advanced further in technique and accomplishments than in any previous year.

DISCUSSION

S. Powers,* Tulsa, Okla. (written discussion).—In northern Oklahoma—the part north of the Arbuckle Mountains—the initial oil development commenced before 1900 in sands of Pennsylvanian age at depths less than 1000 ft. Because of a regional west dip of 20 to 50 ft. to the mile, oil was found at greater depths as development extended westward. By 1917 wells were being drilled to depths of from 1800 to 2500 ft. and most of the oil was still produced from more or less lenticular sands in the Cherokee formation at the base of the Pennsylvanian section, except in the Cushing

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field, where much of the oil is now known to have come from the eroded Ordovician surface. The "Mississippi lime" was considered the lower limit of production.

Between 1917 and 1919 many wells were drilled below the Mississippi lime and the producing horizons, which were first called "breaks in the lime," were proved in 1921 by fossil evidence to be of Mississippian, Devonian, and Ordovician ages in different fields. It became apparent that the "Mounds" sand, discovered near the southwestern edge of Glenn pool in 1908, and the "Wilcox" sand (named from H. F. Wilcox, of Tulsa), discovered at Bixby in 1914, were Ordovician in age and correlated with part of the Simpson formation of the Arbuckle Mountains. The Wilcox sand, to use the popular name, was found productive during and after 1918–1919 in many small anticlines beneath surface noses in the Tulsa-Okmulgee-Stroud area, but the importance of this horizon was not appreciated until after its discovery in the Tonkawa field in 1924.

In 1929 oil was being sought far west and southwest of the fields of 1900 and 1917, in rocks of Ordovician age, at depths ranging from 4000 to 6500 ft. The Wilcox sand of the Simpson formation and the "siliceous lime" (upper surface of the Arbuckle limestone) were the formations of Ordovician age being tested. Stratigraphically, the Arbuckle limestone is the oldest sedimentary formation in the stage except for Reagan sandstone overlying the pre-Cambrian granite. One well on the Mission anticline on the Seminole Uplift was being drilled deep into the Arbuckle limestone in hopes of finding deeper production. Little attention was paid in 1929 to production in formations of Pennsylvanian and Mississippian ages except where oil or gas was found by accident in rotary drilling or in pulling casing from abandoned or unproductive "Wilcox" sand wells.

Structurally, the important discoveries in the past few years have been the presence of buried uplifts and truncated anticlines (partly if not mostly, showing buried topographic as well as structural relief, and therefore being buried hills). The Seminole Uplift has proved to be a structural plateau on which are superposed a number of low, broad anticlines most of which produce from the "Wilcox" sand or associated sands and a few from the Hunton limestone.

"Southern" Oklahoma has not been economically important for several years. Most of the oil is found in sands or sand zones of Pennsylvanian age, which are correlated with difficulty in individual fields. Some of the fields overlie buried hills of Ordovician limestone, others are on relatively steeply folded anticlines between the Arbuckle Mountains and the truncated Ordovician hills. Very little oil has been found in the Ordovician, probably because of the deep truncation and scarcity of anticlines, for most of the buried hills are suspected to be tilted fault blocks.

During 1929, determinations of the age of cuttings from wells reaching granite or schist proved that the Reagan sandstone of Cambrian age is more wide-spread than previously suspected and that it rests on the pre-Cambrian crystallines beneath the sharply folded, buried hills of Ordovician limestone, which compose the "Red River arch." The earliest folding was post-Ordovician (early Pennsylvanian?). The Cambro-Ordovician sandstones and limestones were deposited over a smooth peneplain; the Pennsylvanian shales were deposited over a region of comparatively great relief (1000 ft. or more).

In northern Oklahoma the lowest Paleozoic rocks were deposited on a peneplain with many monadnocks at least 500 ft. high, but the Pennsylvanian seas spread over a peneplain with gentle topographic relief of not over 200 ft. except the monadnocks of Cushing, the Nemaha Mountains, and associated and similar structures, which had relief of 150 to 300 ft. or more. The difference in the topography between northern and southern Oklahoma in the Pennsylvanian are accounted for by the early Pennsylvanian folding of southern Oklahoma as contrasted with the pre-Pennsylvanian folding of northern Oklahoma.

Future oil production is expected in northern Oklahoma in rocks of Ordovician age, which probably extend westward and underlie the western half of the state. The problem is to find the anticlines. Most of them are concealed from the observations of the surface geologist and await discovery by core drilling and by geophysics. The possibility of profitable production from sands of Pennsylvanian age in this western area is untested, but the present expectation is for small wells, unless associated with profound unconformities.

The economics of the petroleum industry have changed. Depth of drilling increases. Size of individual wells increases. Cost of leasehold rises steadily. Price of oil remains constant. Small wells are therefore unprofitable. The hope for Oklahoma lies in the discovery of more large anticlines like Oklahoma City in the western half of the state, because dry holes are closely spaced in the eastern half and the drill will soon have tested the entire sedimentary column of rocks under each large oil field or group of oil fields.

Petroleum Development in West Texas and Southeast New Mexico in 1929

By R. E. Rettger,* San Angelo, Texas

(New York Meeting, February, 1930)

The area referred to in this paper is the southern part of the Permian Basin lying in southwest Texas and southeast New Mexico (Fig. 1).

Fig. 1.—Producing areas of West Texas and Southeast New Mexico. Developments during 1929 are shown by the arrows.

Those fields lying along the northern rim of the basin; namely, the Panhandle fields, are not included. The fields within this area are

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rather similar in regard to their structural and stratigraphic features. Oil is found in Permian limestones (sometimes sand) which have been folded into domes and elongated ridges. These folds are often of considerable magnitude, both areally and in amount of vertical uplift.

During the last two years extensive development has taken place. Within this area 22 refineries with a total daily capacity of 100,700 bbl., and seven gasoline plants with a combined daily output of 110,418 gal. are now operating. Ten major trunk pipe lines to refining centers outside of West Texas have a daily capacity of 391,000 barrels.

During 1928 Texas produced 255,021,000 bbl. of oil of which West Texas and southeast New Mexico contributed 120,651,932 bbl. or 46 per cent. During 1929, Texas produced 299,421,497 bbl. of oil of which West Texas and New Mexico contributed 124,211,518[1] bbl. or 41 per cent. The West Texas daily average increased from 355,000 bbl. at the beginning of the year to a maximum of 395,000 bbl. in July, a fluctuation which is considerably less than that of 1928 when there was a low daily average of 260,750 bbl. and a peak of 406,318 bbl. This greater stability of output is, in a large part, due to the successful operation of proration agreements in the Yates and Howard-Glasscock fields and to the normal decline and proration of the Hendricks field. With the three main producing areas thus under a definite control, a general uniform volume of production has been maintained in 1929 and can be expected in 1930. The average daily production during 1929 has been maintained at about 370,000 barrels.

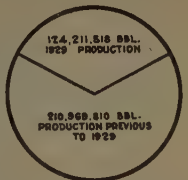

FIG. 2.—TOTAL PRODUCTION WEST TEXAS AND SOUTHEAST NEW MEXICO. ENTIRE CIRCLE REPRESENTS 335,181,328 BARRELS.

TABLE 1.—*Comparative Yields by Fields*

Field	1929 Production,* Bbl.	Percentage of Total	1928 Production, Bbl.	Percentage of Total
Hendricks pool	50,114,411	40.3	58,916,626	48.9
Yates	31,116,094	25.0	22,760,385	18.9
Church-McElroy-McCamey	16,300,159	13.3	25,269,757	20.9
Big Lake	6,296,536	5.1	6,993,931	5.8
Howard-Glasscock	15,083,109	12.2	4,688,929	3.9
Westbrook (Mitchell)	901,121	0.78	1,084,596	0.89
World (Crockett)	638,681	0.48	818,777	0.68
Others	3,761,387	3.02	118,931	0.09
Total	124,211,518	100.10	120,651,932	100.06

* Production for December, 1929, has been estimated. Other figures are compiled from monthly reports of West Texas scouts.

[1] Production for December, 1929, has been estimated.

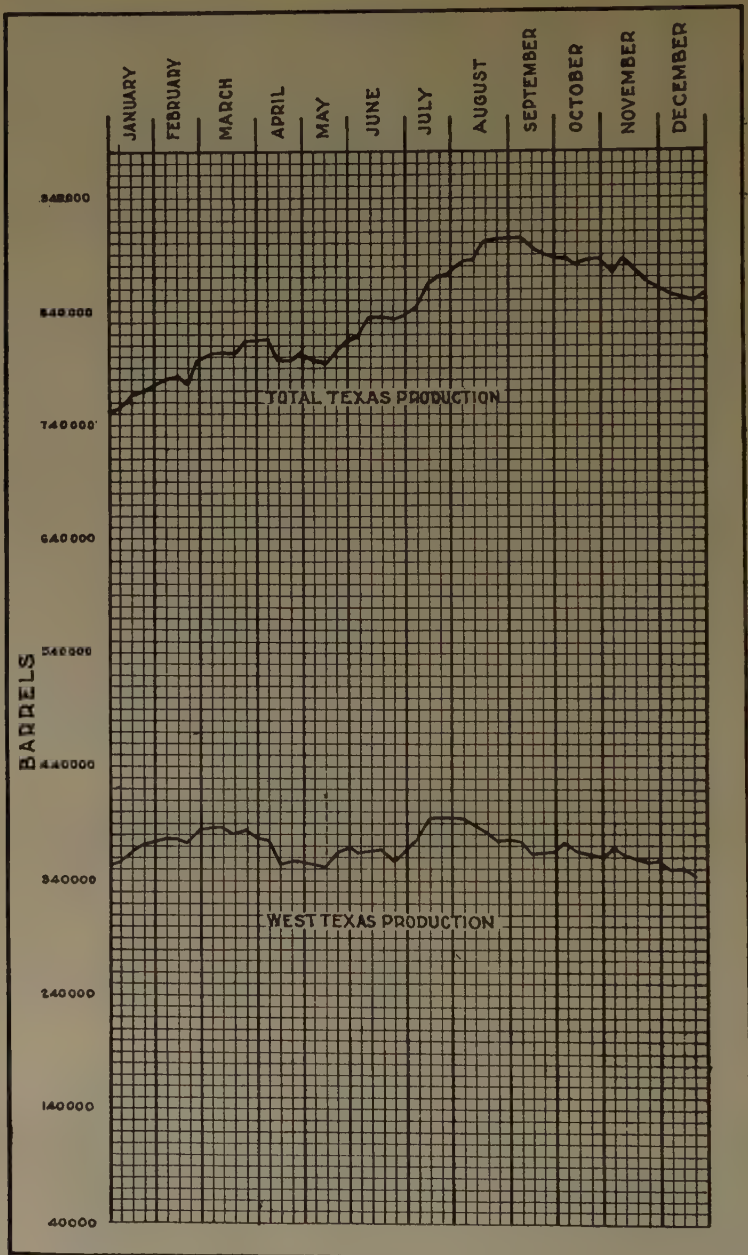

FIG. 3.—COMPARISON OF 1929 DAILY AVERAGE PRODUCTION OF WEST TEXAS FIELDS AND THE ENTIRE STATE. (A. P. I. REPORTS.)

Fig. 2 shows the relative importance of the 1929 production. The entire circle represents the total amount of oil produced in West Texas since the beginning. The smaller quadrant shows that which was produced in 1929—a strikingly large proportion.

The relationship of West Texas and southeast New Mexico to the entire state is shown on Fig. 3. During 1929, 1041 wells were completed in West Texas and New Mexico, of which 702, or 67 per cent., were oil wells; 22, or 2 per cent., were gas wells; and 317, or 30 per cent., were failures. During 1928, the percentage of oil wells to total completions was 74. The fact that the percentage is smaller this year is due to the increased wildcat activity largely in Pecos County.

New Developments

Glasscock County

With the completion of the World Oil Co. McDowell No. 1 in sec. 21, block 34, T. 2 S., T. & P. Survey, as a small producer, an apparent 6-mile southwest extension to the Howard-Glasscock field was proved. Subsequent development near the discovery well, however, has been disappointing, and its true significance is not yet known. About 4 miles northeast of the World well and about 2 miles southwest of the main field, Kirby-Black Arrow-Atlantic completed their Phillips No. 1 as a small well in sec. 23, block 33, T. 2 S., T. & P. Survey. This well has been off-set and the adjoining area tested with encouraging results. Production is found at a depth of between 2100 and 2300 ft., about 200 ft. below the top of the Big Lime. Wells so far completed in this area have had initial productions averaging from 1300 to 1400 bbl. They are now under proration and operators have agreed to run not more than 30 per cent. of their potential production, which is estimated at 16,000 bbl. per day from 16 wells. The gravity of the oil ranges from 30° to 33°, being from 1° to 4° higher than that from the deep pay in the old field to the northeast. This extension to the Howard-Glasscock field makes the field one of major importance. In 1930 it should show a substantial increase in production, unless too greatly restricted by proration.

Mitchell County

In the early part of 1929, the Simms Oil Co. Ellwood No. 1, sec. 29, block 18, S. P. Survey, encountered 12,000,000 cu. ft. of sweet gas at 606 ft. This was cased off and the well drilled to 4725 ft. without further showings. Since that time a second shallow gas well has been drilled nearby, producing about 5,000,000 cu. ft. of gas. To date this gas is not being utilized.

Pecos County

Pryor Field.—In May, 1929, the Phillips Petroleum Corpn. Pryor No. 1, located in sec. 78, block OW, about 9 miles west of Fort Stockton,

encountered a lime pay horizon at 1345 to 1350 ft. which tested for about a 100-bbl. well on the pump. This well, however, was started for a deep test, so the oil was cemented off and drilling continued to 4375 ft. where the hole was plugged and abandoned. Subsequently a dry hole has been drilled west of the original well and another about one-half mile east. A 100-bbl. well has been recently completed slightly southeast of the original well, and another test is now drilling. From the results so far obtained, it is expected that this shallow field will not assume any great importance.

Taylor-Link Field.—This field is located 20 miles west of the Yates field and is so named because the discovery well was drilled by the Taylor-Link Oil Co. This well is located in sec. 30, block 16, University Survey, and was completed in June of this year for 30 bbl. per day. The pay horizon was encountered at 1613 ft., 228 ft. below the top of the Big Lime. The gravity of the oil is 30.7°. Subsequent development has shown the presence of another pay at an average depth of 950 ft. At this writing 30 wells have been completed either in the 1600-ft. pay or in the 950-ft. pay. Dry holes to the northeast, east and south apparently define the limits of the field in those directions. Total production during November was 232,441 bbl. Unless additional productive area is found to the west, it is doubtful if this figure will be exceeded.

Pecos Valley Field.—This field lies 25 miles north of Fort Stockton and was discovered in November, 1928, by the Pecos Valley Oil Co. Fee No. 1, sec. 22, block 10, H. & G. N. Survey. This well was completed at 1628 ft. for a production of 105 bbl. daily. The pay zone is probably just above the Big Lime. At the present time, there are seven producing oil wells and two gas wells in the field. They are small, having a total daily output of only 122 bbl. and are rather widely separated. Several dry holes among them suggest that the production will be spotted and never very large.

Masterson Well.—S. B. Owens et al. Masterson No. 1, sec. 104, block 10, H. & G. N., apparently opens up a field between the Pecos Valley area and the Taylor-Link field. It is now producing about 100 bbl. oil per day from a total depth of 1495 ft. Oil was first encountered at 1265 to 1270 ft. with an apparent increase at 1435 to 1439 ft. The upper pay is above the Big Lime. The possibilities of this area are unknown since at this writing no further development has taken place.

Ector County

R. R. Penn Kloh No. 1, sec. 7, block 44, T. 3 S., T. & P. Survey, was completed in November at a depth of 3744 ft. for an initial production of 365 bbl. per day flowing through tubing. This well appears to be an eastward extension of the Texas (Cosden) Connell field lying about 2½

miles to the southwest. The production is coming from the Big Lime. At the present time there are five wells drilling in the area whose outcome will probably indicate whether or not the field will assume major importance. If large production should be found, a drilling campaign will necessarily follow because of the varied lease ownerships and small tracts.

Andrews County

The presence of a field is indicated in Andrews County by the showings in the Deep Rock Ogden No. 1, sec. 6, block A-46, Public School lands. In this well 2,500,000 cu. ft. of gas was encountered at 2925 ft., oil at 4305 to 4309 ft. with an increase at 4345 to 4348 ft. Swabbing tests indicate a production of about 250 bbl. On deepening to 4428 ft. sulfur water was encountered. A dry hole 1½ miles to the east limits the field in that direction. No other tests have been drilled, and the importance of this discovery cannot now be foretold. Unquestionably there may be considerable development here during 1930.

Ward County

Shipley Field.—The Shipley area, located in southeastern Ward County, has developed into a small field. At the present time there are 10 completed wells producing from 10,000 to 15,000 bbl. per month. To date the field has produced 141,132 bbl. The most interesting recent development in this field is the result of the deepening of the Shell Sloan No. 1 which is located in sec. 16, block 5, H. & T. C. Survey, southwest of the producing area. Sulfur water was encountered in the regular Shipley pay from 2530 to 2534 ft. Upon deepening, several pays have been encountered from 2658 ft. to the total depth of 3070 ft. No definite production record has been obtained, but it seems evident that a new pay zone has been found for this area, and the possibilities of a deep field are favorably considered.

Grand Falls Area.—About 2 miles southwest of the Shipley field and in Grand Falls town site, the Alpine Oil Co. town site No. 1 was completed at a total depth of 2150 ft. for an initial production of 24 bbl. per day. The pay is from a sandy lime at the top of the Big Lime. At the present time there are three wells being drilled in the vicinity of the town site well. It is probable that this field will be similar to the Shipley field.

Bennett Area.—About 5 miles west and a little north of the Grand Falls area, Penn and Atlantic have apparently discovered a new field. Their Bennett No. 1 which is located in sec. 16, block 34, H. & T. C. Survey, topped a pay at 2427 ft. The well was deepened at intervals to a total depth of 2621 ft. and plugged back to 2618 ft. when water appeared. It was shot several times and finally completed for an initial production of 149 bbl. per day. It opens a large area for drilling, some of which will

no doubt take place in 1930. To date no other wells have been completed, although a second one is being drilled.

O'Brien Field.—This field which seems to be on the south extension of the main Winkler fold was opened up by the Gulf Production Co. which owns a large block of acreage apparently including most of any oil field which may be developed. To date, development has been confined to determining the extent of production. Wells have been drilled about 1 mile apart and have proved an area some 4 miles long. Four wells have been completed with a total daily output of a little more than 1000 bbl. Most of this production is coming from O'Brien No. 4 located in sec. 19, block F., G. & M. M. B. Survey. The oil in this area is sweet and tests 38.6° gravity, thus being a better quality than that found to the north in Winkler County. As the bulk of the acreage is owned by one company there will probably not be any rapid drilling campaign.

Reagan County

In November, 1928, the Texon Oil & Land Co. completed its University 1-B at a total depth of 8525 ft. for an initial production of about 1000 bbl. per day of 56° gravity oil. This is the deepest production to be found in the Permian Basin and no doubt will stimulate deep drilling in other localities. During 1929 the daily production of this discovery well has gradually increased so that now it averages 2800 bbl. of oil and 27,000,000 cu. ft. of gas. Gasoline is extracted from the gas and arrangements are being made to dispose of the residue. As there is no market for oil of 56° gravity, the well is being run directly into the field tanks, bringing up the general gravity of the total field. To date this one well has produced 930,000 bbl. of oil.

The Big Lake Oil Co. which owns the adjoining lease has completed two deep wells within the last year. They are the University 3-C and 4-C and have total depths of 8385 and 8220 ft., respectively. They are good for about 200 bbl. per day each. These wells have undoubtedly not yet encountered the big pay which is producing in the discovery well, and they will probably be drilled deeper. The top of the Big Lime in this field is encountered at about 2800 ft., making the producing horizon 5745 ft. below the top.

Schleicher County

Schleicher County is located on the southeastern rim of the Permian Basin and to date has had very little drilling activity. Favorable oil showings were obtained during the past year in the Phillips (Interstate) Whitten No. 1 located in sec. 35, block LL, T. C. Survey, a few miles north of the town of Eldorado. While standing at a total depth of 4925 ft. this well made several flows of oil which tested 36°. Casing was run in order to condition the hole, and it is probable that some of the pay

was cased off as the well ceased to flow. Further drilling to a depth of 5620 ft. has failed to show any additional pays. This well is still drilling and will be carried as deep as possible. The showings in this well open up an immense territory for future testing.

Lea County, New Mexico

Drilling activity in Lea County during 1929 has been confined largely to the development of previously known structures. The northward extension of the Winkler County fold has been traced for about 30 miles and is known as the East Lea County high. Results, however, have been somewhat discouraging owing to the fact that the gas area has proved to be much larger than anticipated. It is now apparent, as far as this structure is concerned, that oil will be found only along a narrow strip flanking the gas area on the west. Wells completed along this strip have not been phenomenal producers. Besides the foregoing, three new producing areas have been discovered, and the Hobbs field has developed to a sufficient extent to show that it will probably be a field of major importance. Total production for Lea County in 1929 amounted only to 540,000 barrels.

Hobbs Field.—In December, 1928, the Midwest State No. 1, located in sec. 9, T. 19 S., R. 38 E. was completed at 4220 ft. for an initial production of 696 bbl. The pay horizon is near the top of the Big Lime. During 1929, five oil wells and one dry hole were completed in the immediate vicinity. The Midwest Leech No. 24, 1¼ miles to the south, had an initial yield of 800 bbl. per day; the Walker Terry No. 1, ¾ mile southeast, of 550 bbl. per day; the Midwest Capps No. 1, a northeast offset, of 720 bbl. per day; and the Ohio State No. 1, ¾ mile to the southwest, of 35 bbl. per day. The Humble Bowers No. 1, 3 miles to the northwest, is now drilling at 3930 ft. after having discovered a new pay horizon stratigraphically above that which is producing in the Midwest State No. 1. This well was estimated good for 450 bbl. per day at a depth of 3402 ft. This production, however, has been passed up in an attempt to test out the Big Lime pay. The above development indicates that the Hobbs field is at least 4 miles long and 1 mile wide. It is quite likely that considerable development will take place here during 1930 as lease ownerships are fairly small, and attempts to curtail drilling have been unsuccessful. At the present time there is no outlet for the oil produced, so that most of the wells are shut in.

Lea Field (Lynch Field).—The Lea field was discovered in March, 1929, when the Texas Production Co. completed its Lynch No. 1 at a total depth of 3731 ft. for an initial production of more than 1000 bbl. At present it is pumping an average of 900 bbl. per day. In September, Cranfill and Reynolds completed their No. 1-B State located about 1 mile

south of the discovery well for an initial production of 1284 bbl. and their 2-B State for 255 bbl. At this time there are nine drilling wells in the area. The Texas Pipe Line Co. is running the oil. The limits of the field have apparently been determined by dry holes to the northwest and to the southeast, indicating an extent of not more than 3 miles in those directions. It is thought that this field will not assume any great importance. It should reach its peak of production during 1930.

Henry Area.—In December, 1929, the T. P. Coal & Oil Co. completed its State No. 2, sec. 21, T. 23 S., R. 36 E., at 3721 ft. for an initial production of 500 bbl. daily. Earlier attempts to find production in this area resulted in gas wells. The T. P. Coal & Oil Co.'s State No. 1, about 1½ miles to the east, was completed at 3668 ft. with 15,000,000 cu. ft. of gas. Marland Oil Co.'s Lynn No. 1, about 1½ miles southeast of State No. 1, was completed at 3930 ft. for 50,000,000 cu. ft. of gas. A dry hole to the northwest suggests that the oil field will occupy a narrow strip trending almost due north and south. This is on the steeply dipping west flank of the East Lea County high, and development will probably be difficult because of gas and water troubles.

Eunice Area.—This area is located about 18 miles south of the Hobbs field along the East Lea County high. In April, 1929, the Marland Oil Co. completed its Lockhart No. 1 at 3990 ft. for an initial production of 230 bbl. per day. It is located in sec. 31, T. 21 S., R. 36 E. The other attempts to the south and to the east by the Empire Oil Co. and the Gypsy Oil Co. resulted in large gas wells. At the present time the Marland Oil Co. is completing its A. E. Meyer No. 1, 3 miles north of its Lockhart No. 1. This well is estimated good for 65,000,000 cu. ft. of gas and 600 to 1000 bbl. of oil per day. Production is being killed in an effort to drill deeper. The extent and importance of this discovery cannot be predicted at this time.

Vacuum Well.—The Vacuum Oil Co. has recently completed its State No. 1, located on the line between sec. 13 and 14, T. 17 S., R. 34 E. at a depth of 4900 ft. for an initial production of 120 bbl. per day. While this production is not in itself important, its location between the Hobbs field and the old Maljamar field suggests a continuous trend between the two areas.

Pool Development

The year of 1929 has been very quiet as far as new development in major fields is concerned. The Hendricks pool is definitely on the decline, the Yates pool is strongly controlled by proration, the Church-Fields-McElroy pool is practically at a standstill, and the Howard-Glasscock pool is under semirigid proration control. There has been no intensive drilling activity except locally in the Taylor-Link field in Pecos County, in which area only 30 wells have been completed.

Table 2 shows 1929 and total production of each field in West Texas. Fig. 4 shows total production since discovery of the principal fields of the West Texas Division.

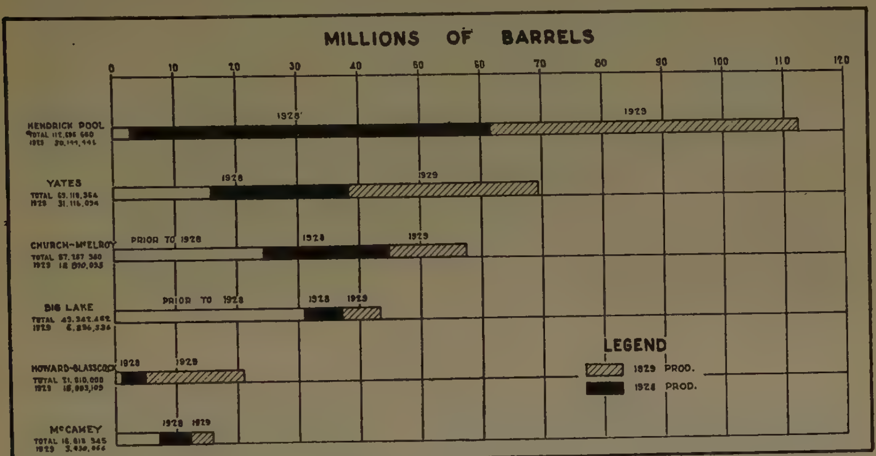

FIG. 4.—TOTAL PRODUCTION SINCE DISCOVERY OF THE PRINCIPAL FIELDS OF THE WEST TEXAS DIVISION.

TABLE 2.—*Production by Fields, West Texas, 1929 and Total*

Field	Total Production since Beginning, Bbl.	Field	Production in 1929,* Bbl.
Crane	57,267,380	Crane	12,870,093
Waddell (Crane)	22,998	Waddell	14,287
Powell (Crockett)	2,333,245	Powell	638,681
Connell	21,698	Connell	12,339
Fisher	633,479	Fisher	437,947
Howard-Glasscock	21 010,000	Howard-Glasscock	15,083,109
Jones	3,093,102	Jones	1,423,117
Wheat (Loving)	327,319	Wheat	249,329
Westbrook	6,801,806	Westbrook	901,121
Pecos Valley	30,000	Pecos Valley	30,000
Taylor-Link	537,955	Taylor-Link	537,955
Yates	69,118,364	Yates	31,116,094
Big Lake	43,342,462	Big Lake	6,296,536
Skelly (Reagan)	68,622	Skelly	41,918
Runnels	77,764	Runnels	20,849
Ira (Scurry)	29,079	Scurry	7,013
McCamey	16,813,345	McCamey	3,430,066
Hayzlett	141,132	Hayzlett	136,025
O'Brien	280,628	O'Brien	280,628
Hendricks	112,686,660	Hendricks	50,144,411
Lea County, N. M.	546,290	Lea County, N. M.	540,000
Total	335,181,328	Total	124,211,518

* December production estimated. Maximum error not more than 0.1 per cent.

Hendricks Pool

At the present time there are 560 wells in the Hendricks pool (including the Leck area to the north and the Sealy area to the south) producing 121,451 bbl. of oil daily. This figure is supposed to represent the proration allotment, but actually it is all that the operators care to produce, owing to the serious water situation. Practically every well in the field is showing water from 1 to 99 per cent. It is believed the entire field would go to water in a short time if the wells were allowed to produce their potentials. During 1929 the Hendricks pool produced 50,144,411 bbl. of oil and has produced since the beginning 112,686,660 bbl. According to proration agreements, a total of 8,360 acres is considered proved, making a total average recovery so far of 12,748 bbl. per acre. During 1930 there should be a material decrease in the production.

Yates Pool

The Yates pool now has a daily potential production (based on hourly gages) of 5,314,832 bbl. from 537 wells. This is an average daily potential of approximately 10,000 bbl. per well. The actual production is limited by proration agreements to 130,000 bbl. per day. During 1929, the Yates pool produced 31,116,094 bbl. of oil, and since beginning (September, 1927) it has produced 69,118,364 bbl. Taking an estimate of 16,000 acres as proved, the recovery per acre to date is 4319 bbl. R. V. Hennan and R. J. Metcalf[1] estimate a total recovery of at least 40,000 bbl. per acre or a total for the field of 640,000,000 bbl. They say that a total of 800,000,000 bbl. is not an improbability. With the decline in production evident in the Hendricks pool, it is probable that the proration allowance of Yates will be increased. This should put Yates in first place for production in 1930.

Church-McElroy Pool

The Church-McElroy pool produced 12,870,093 bbl. of oil in 1929. Its total production since March 1926 of 57,267,380 bbl. gives a total average per acre yield of 20,452 bbl. considering each of the 280 wells as draining 10 acres. The northern part of this field (Church) is almost completely drilled up, while the southern part is being held as a reserve by the Gulf Production Co. Total recovery per acre from this field is estimated at about 30,000 barrels.

Howard-Glasscock Pool

During 1929 the Howard-Glasscock pool produced 15,083,109 bbl. of oil, nearly three times as much as all previous total production. The

[1] Ray V. Hennan and R. J. Metcalf: Yates Oil Pool, Pecos County, Texas. *Bull.* Amer. Assn. Petroleum Geol. (1929) **13**, No. 12, 1509–1556.

total production to date is 21,010,000 bbl. from about 416 wells. Estimates on recovery per acre are not available at this time, since there are five different producing horizons, each confined to certain localities. Some leases are producing from as many as four different pays. Estimates for total ultimate recovery per acre vary from 10,000 to 25,000 bbl. Two of the pay horizons are above the top of the Big Lime, and three are below. They are generally listed as the 1300, 1800, 2200, 2500 and the 3000-ft. pays. Of these, the upper two are sands, producing a sweet oil of 33° to 34° gravity. The others are dolomitic, producing oils ranging from 26° to 33° gravity. In general the gravity decreases and the sulfur content increases with depth. This field should show a material increase in production during 1930 unless held in check by proration.

Summary

Oil or gas was discovered in 15 different localities during the past year in West Texas and southeast New Mexico. Up to the present time, however, no one of these discoveries has been proved to be of major importance. It is known that several are definitely inconsequential, while the others are still in an undeveloped state. The total production from West Texas and southeast New Mexico in 1929 was slightly greater than in 1928. Indications are that unless the proration runs in the Yates field are increased, there will be a small decline during 1930. The Hendricks pool has definitely passed its peak so that in 1930 it should produce considerably less than it has in 1929. The Yates field, on the other hand, has now its greatest potential production—over 5,000,000 bbl. per day. No doubt, in order to keep the pipe lines at capacity, the production allowed from this field will be increased.

The production during 1928 and 1929 forms the great bulk of the total oil recovered in West Texas. The 1929 production alone amounts to about 40 per cent. of the total oil produced in this area since discovery 9 years ago. (Fig. 2.)

The 8500-ft. well in the Big Lake pool has gradually increased its production from 1000 to about 2700 bbl. per day of 56° gravity oil. Other wells recently drilled nearby indicate that a new deep field has been discovered.

During the next few years, probably there will be a renewed activity in search of oil at depths below 8000 ft. There are numerous localities where such drilling is contemplated and will no doubt be started when conditions warrant.

The development in southeast New Mexico has shown that the great East Lea County high, extending for 30 miles northward from the Hendricks pool, is not going to be as prolific an oil producer as was expected about a year ago. Recent tests have shown a tremendous gas reserve

with probably only a narrow zone of commercial oil production along the west flank.

The Hobbs field, situated north of the East Lea County high has shown some characteristics of a major oil field. Two pay horizons have been discovered and favorable structural conditions have been partly outlined. Several wells now drilling should prove or disprove the importance of this area. Should large wells be completed, there will be a heavy drilling campaign with a period of considerable flush production. At the present time there is no outlet for the oil, but several pipe line companies are postponing development until the magnitude of the field is definitely proved.

As a whole, West Texas and New Mexico have maintained a steady and even production during the past year of about 370,000 bbl. per day. Such production has been possible because of proration agreements and the nondiscovery of any major field requiring immediate drilling.

The total oil produced in West Texas to date is 335,181,325 bbl., of which 124,211,518 bbl. were produced in 1929 and 120,651,932 bbl. in 1928.

DISCUSSION

A. R. Denison,* Fort Worth, Texas (written discussion).—Production for Texas increased more than 55,000,000 bbl. during 1929, which represents more than 17 per cent. increase. Production in West Texas and New Mexico increased approximately 4,000,000 bbl., which is slightly more than 3 per cent. The above figures indicate very clearly the results of restriction and proration of the large fields in an important district. The potential production of this area was sufficient to have produced perhaps twice as much oil as was actually taken from the ground. Without restricting measures it could have easily caused a serious overproduction for the entire United States. The most important field in this territory, namely, the Yates pool, has been under restriction since discovery and all other fields are prorated as soon as they appear to have major proportions. Exceptional cooperation has been the main factor in the success of these restrictive measures and it is perhaps not beside the point to say that no field can be developed in West Texas which would seriously threaten the market structure.

While 1929 was a year of numerous new oil discoveries in this territory, the close of the year found none of these which demonstrated new structural conditions which were the equivalent of that present in the known fields of prolific production. Several of these discoveries are represented by only one well, hence, further drilling may indicate favorable structural conditions. At the beginning of the year, however, the outstanding of the numerous discoveries was that by Penn et al. No. 1 Abrams in sec. 7, block 44, T.3 S., T. & P. Survey, Ector County. This area has five drilling wells, which if completed as producers, will stimulate an active drilling campaign due to lease ownership being in small tracts and the fee largely owned by the University of Texas, which has adopted an aggressive development policy on its lands.

Of unusual significance was the discovery of Granite beneath the Permian Basin by the Shell Petroleum Corpn. at slightly below 5000 ft. in its No. 1 University in sec. 23, block 26, University lands, Pecos County. This well was structurally high on the Big Lime, but found only water. This discovery may lead to entirely new

* Division Geologist, Amerada Petroleum Corpn.

conceptions regarding the deeper structure underlying the basin which will be the forerunner of a new prospecting campaign.

Even though two other wells were partly completed in the Big Lake field in the 8000-ft. pay the significance of this discovery is yet unknown. Active prospecting for this deep horizon, underneath other productive structures, will probably be delayed until the basin has been more thoroughly prospected for the producing horizons of lesser depth. At this time, however, it probably is safe to say that only the surface has been scratched in so far as the producing possibilities of the West Texas Basin are concerned.

The outstanding extension to any producing field was that of the Howard-Glasscock pool. The completion of Glasscock Brothers No. 1 Edwards in sec. 18, block 33, T.2 S., T. & P. Survey, Glasscock County, appears to extend the present producing field for another 3 miles. This gives a total productive length of 17 miles for this unusual field. Along this length numerous producing horizons are known. Except for the central portion, formerly called the Roberts pool, little effort has been made to produce from more than one of the known horizons. A large area at the east end of this field remains to be tested in the lime. The western portion has largely exploited the upper pay in the lime, while the lower pays remain to be tested. The sands above the lime in the central and western part of the field have not been thoroughly explored. No production and only a few wells have been drilled below the 3000-ft. pay in any part of the field. Hence, the lower possibilities are entirely unknown.

Lea County further demonstrated in 1929 that it contains structural conditions highly favorable for oil and gas. At the close of the year the wells completed were all below 1000 bbl. in initial production, except in the Lea area. It is believed that production, where found, will be in relatively narrow elongated pools and it is quite possible that the wells drilled to date, which are widely separated, may have failed to uncover the richest part of the productive area. Deeper penetration of the lime in some wells has demonstrated that a great many wells completed for gas have not been drilled deep enough to test the best possibilities for oil production. The extension of the Texas and New Mexico Railroad from Cheyenne in Winkler County northward through Eunice and Hobbs into Lovington and the extension of the Sante Fe Railroad from Seagraves, Texas, into New Mexico, are expected to stimulate drilling development. One pipe line has been projected from the Winkler area northwestward into Lea County and it is believed that the extension of other pipe lines into Lea County only awaits the development of a single prolific area. The coming year should see more active development in Lea County with a greater expectancy of large initial production than was the case in 1929.

E. L. Estabrook,* New York, N. Y.—What is happening in Yates pool? What are they finding out about the nature of the reservoir—are there large, cavernous openings? And how is the well pressure acting; is it remaining constant or showing a decline? Has edge water come in and taken any of the edge wells, as it did in the south fields of Mexico? If there are large cavernous openings the conditions would be similar to the Golden Lane in Mexico, where there was a spectacular movement of the water to some of the big wells. Has that happened in Yates?

C. P. Watson,† Fort Worth, Texas.—The situation in the Yates field has been greatly benefited by the fact that there has been a uniform exploitation of the field over the entire producing area. We know there is edge water on the southeast side, and also on the north side, and there is bottom water, because wells on top of the structure have drilled into it and have plugged back.

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* Consulting Petroleum Engineer, Pan American Petroleum & Transport Co.

† President, Federal Royalties Co.

The degree of porosity varies tremendously. There are certain sections structurally well located, which have very small wells, entirely due to the absence or negligible amount of porosity. The supposition or belief is that the water encroachment will be greatly retarded by the present method of exploitation. So far there has been no water encroachment from the edges beyond the limit that was ascertained about 1½ years ago. The petroleum engineers, I understand, have been compiling estimates of the future reserves in the Yates field.

E. L. Estabrook.—Are they larger than those quoted in the paper—640,000,000 barrels?

C. P. Watson.—Some of them are.

E. L. Estabrook.—How about the well pressure in the field?

C. P. Watson.—No noticeable change at all. It is a remarkable field with production at depths of 1000 to 1700 ft., according to the topographic location of the well; and beyond that they consider with great favor the possibility of deep production in the so-called Pennsylvanian Series at Big Lake.

S. St. Clair,* New York, N. Y.—What are they hoping to get per acre from those fields?

C. P. Watson.—About 15,000 bbl. I believe.

S. St. Clair.—I understand that the Winkler pool up to the present time has produced a little less than 11,000 bbl. per acre?

C. P. Watson.—The trouble there is that the east side of the Hendricks field, although structurally high, has produced insignificant amounts of oil as compared to the portion of the field on the west flank, with the result that when the entire area is taken into consideration the per acre yield is abnormally low. Individual tracts of land in the Hendricks field have produced as much as 50,000 barrels.

S. St. Clair.—Are they estimating that the Yates pool may do that much on at least a large part of the dome? If so, we can get those very high figures, but we cannot if we cut it down even to what the Big Lake pool has produced, that is somewhere around 23,000 bbl. I have often wondered if those high estimates are not like some of our underestimates on the total oil in the United States. Discovery of lower sands, however, may give the field the high production predicted.

C. P. Watson.—The maximum recovery that I have heard is 50,000 bbl. per acre for the Yates field, and those estimates have been put out by conservative individuals.

S. St. Clair.—Up to a short time ago they were figuring that Oklahoma City would probably do 40,000 or 45,000 bbl. per acre. I believe that has been cut almost half recently. I am wondering, if they draw on some of those West Texas pools, whether the estimates will not come down equally quickly. You said that probably the sands in the East Texas area might yield from 50,000 to 75,000 bbl. per acre?

C. P. Watson.—Yes. The basis for these estimates on total per acre yield in East Texas reflects the thickness of the Woodbine sand. The Powell field produced 30,000 bbl. per acre over its proved limits, from approximately 40 ft. of Woodbine sand. With a greater thickness of sand in the Van field, they have revised their estimates of recoverable oil to a higher degree.

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* Consulting Geologist.

S. St. Clair.—If the gas pressure is there to bring it out.

C. P. Watson.—This field is under unit operation and is going to be exploited on the most economical basis, probably, of any field hitherto.

S. St. Clair.—But your statement would not cover all of the East Texas fields even though production comes from the Woodbine sand?

C. P. Watson.—No, my remarks referred specifically to the Van field. There has been a plan on the part of several operators in various producing fields to pool together and drill deep tests on each one of the structures, in the Hurdle field, in the Hendricks field, and also in the Powell field in Crockett County.

Development in East Texas and Along the Balcones Fault Zone, 1929*

By F. E. Poulsen,† Fort Worth, Tex.

The discovery of two new fields, Van, in East Texas, and Darst Creek, in the Balcones fault zone, is the outstanding development in 1929. The first six months was one of the most inactive periods in the history of East Texas. Five of the interior salt domes, which had been so eagerly sought as a result of the Humble Oil & Refining Co.'s strike on the Boggy Creek dome in 1927, were drilled with discouraging results, and the Boggy Creek field itself had fallen far short of expectations. Kelsey, a structure of considerable magnitude and extent in Upshur County, was equally disappointing; the Amerada Petroleum Corpn.'s initial test on this structure was dry. The situation improved in the latter half of the year. On Oct. 13, 1929, the Pure Oil Co. discovered the Van field. This gained for East Texas a permanent place in point of future potential production.

There was a similar reaction in the Balcones fault zone. The Salt Flats (Bruner) field, the important discovery of 1928, proved its rating as a second Luling, but on account of repeated failures to extend the productive zone, wildcatting during the first half of 1929 in the Luling district was dilatory. In July, however, Darst Creek, a third fault-line field of majori mportance producing from Edwards limestone (Lower Cretaceous), was discovered. Retarded as development in this field has been by various attempts at proration, interest in the Balcones fault zone fields centered on Darst Creek as the year 1929 drew to a close.

Development in East Texas

Fields Discovered during 1929

Van.—The discovery well, Jarman No. 1 of the Pure Oil Co., is near the town of Van in the southeastern part of Van Zandt County, Texas. It is 55 miles northeast of the Powell field in Navarro County and 45 miles west of north from the Boggy Creek field in Cherokee and Anderson counties.

Early in 1927, the Van area was submitted to seismographic exploration and outlined as a large anticline, the apex of which seemed to be

* Published with permission of T. Wasson, Chief Geologist, The Pure Oil Co.

† District Geoloist, Pure Oil Co.

just north of the town of Van. Later, a detailed survey of the areal and structural geology of the region indicated that Van was located on a large Wilcox (Eocene, Tertiary) inlier, surrounded by younger Claiborne beds.

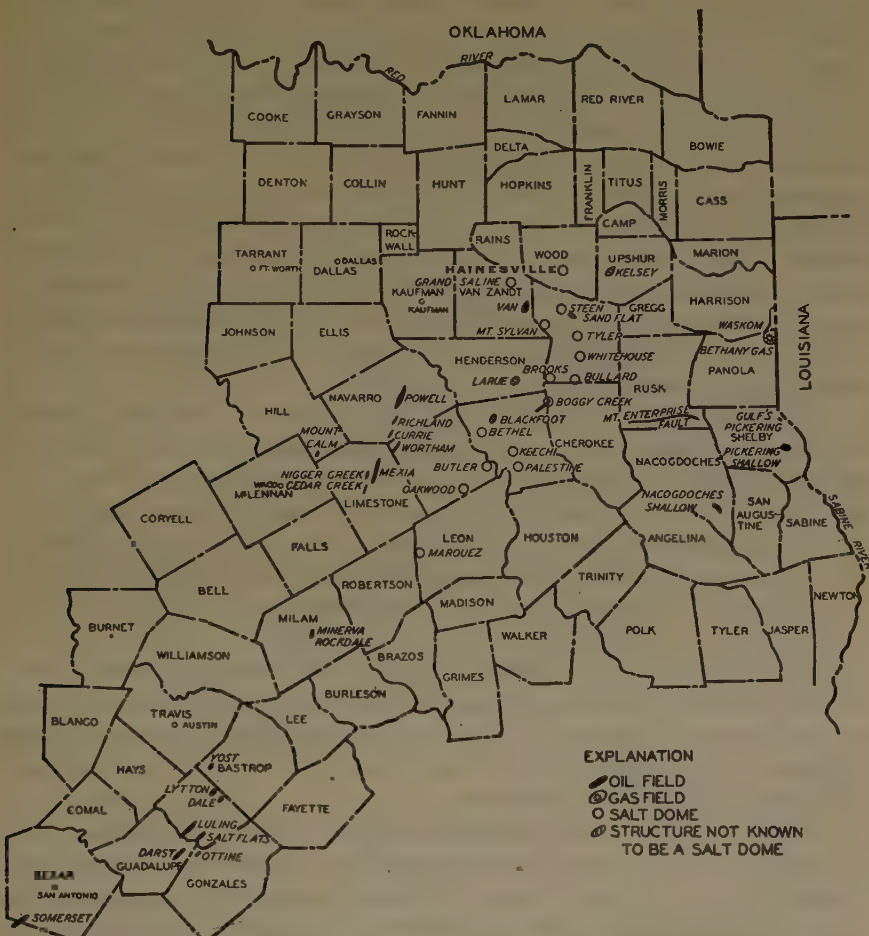

FIG. 1.—OIL AND GAS FIELDS, SALT DOMES AND IMPORTANT STRUCTURES IN EAST TEXAS AND BALCONES FAULT ZONE.

Core drilling which began on the Van structure in January, 1929, on locations established from the geological and geophysical surveys, was completed in July, 1929. In some of the core holes on top of the dome, oil and gas at shallow depths were encountered, the best showings being in the Nacatoch sand (Upper Cretaceous) which lies between depths of 1100 and 1300 ft. The coring confirmed earlier geological and geophysical work in indicating a domed anticline of great magnitude. Four

commercial wells, Jarman No. 1, Thompson No. 1, Tunnel No. 1 and Tunnel No. 2, were completed.

The maximum amount of Woodbine penetrated is 320 ft.; it is not known how much more of the formation is present. In Tunnel No. 2, the top of the pay in the Woodbine was reached at 2426 ft. and to the depth of 2666 ft., 143 ft. of saturated sand was found. This well is still in saturated sand to its present depth. The thickness of the individual sand bodies in the Woodbine varies from a few feet to at least 87 ft. The lowest sand body in Tunnel No. 1 was penetrated 87 ft. and there appeared to be no change in character or saturation at the depth at which the well was completed.

The Van field is primarily a large uplift on the top of which there is considerable faulting, but it is believed that in addition to the faulting, there are structural complications due to squeezing of the less competent beds. The structure appears to be uplifted approximately 2000 ft. above normal and its influence on subsurface beds is reflected for at least 20 miles from the top of the structure.

The average gravity of the oil is 35.8°. It is a sweet oil, having a higher paraffin content than is found in the Woodbine sand in the Mexia-Powell fault-line fields. The field is being operated under a unit plan by which the Pure Oil Co., which has been conceded 85 per cent. of the probable productive acreage, has complete charge of all development.

The average time from the beginning to the completion of a well in the field is one month. Since no water has been encountered on the structure, surface pipe is set at depths between 200 and 300 ft. and 7-in. (o.d.) casing just above the Woodbine sand. A 10-in. pipe line has been completed from the field to a 70-car loading rack on the Cotton Belt R. R. at Chandler, 18 miles south. As soon as the field is more definitely outlined, the line will probably be extended to the Smith's Bluff refinery of the Pure Oil Co. near Beaumont.

Shelby County.—Active interest in Shelby County was revived for a short time early in 1929 when Pickering Lumber Co. No. 1 of the Gulf Production Co., 9 miles northeast of Shelbyville and 8 miles north of the old Pickering (shallow) field, encountered 4,000,000 cu. ft. of gas and 154 bbl. of 37.8° gravity oil from a new horizon at a depth of 3382 ft. The location was made on a supposed magnetometric high. After being deepened with hope of increased production, the oil and gas decreased, and the test was finally completed at 3440 ft., making 30 bbl. of oil and 4,000,000 cu. ft. of gas. Subsequent wells in the area missed production.

Fields Discovered Previous to 1929

Boggy Creek (Salt Dome).—Boggy Creek is in the Neches River Valley, in Anderson and Cherokee counties 10 miles west of Jacksonville. The

field was discovered in 1927 and became the first productive interior salt dome in Texas. It has been developed slowly by the Humble Oil & Refining Co., which controls the acreage in a large block. Boggy Creek is unusual in that production is confined to a narrow strip one location wide and 4 miles long, along a line which strikes southwest from the dome. Faulting is undoubtedly a factor in the accumulation. Production is from the Woodbine (Bingen) sand (Upper Cretaceous), and is found at a depth of approximately 3700 feet.

In February, 1929, the pipe line for the Humble Oil & Refining Co. was completed—an 8-in. line from the field to Groesbeck in Limestone County, where it joins the Humble's trunkline system extending southward to the Gulf Coast—and the running of crude commenced. The wells were opened after having been choked for many months. Previous to the opening of the wells the daily production of the field was 3575 bbl., and a 24-hr. gage after some of them were opened increased it to 5100 bbl., the largest day's production the field has had. Since the wells which were opened started immediately to increase in percentage of salt water, they were again partly choked.

At the close of 1929, the daily average production was 3778 bbl. from 19 wells. There are also three gas wells in the field. Twenty-nine dry holes have been drilled. The largest well to date in the field, Todd A-1, produced 380 bbl. per hr. through ¾-in. choke, initial production. Boggy Creek has produced to date a total of 1,500,000 bbl. of oil.

Prospects Discovered Previous to 1929

Bethel (*Salt Dome*).—This interior salt dome is in Anderson County, 20 miles northwest of Palestine, and 2 miles south of the village of Bethel. It was discovered in 1927 by a Pure Oil Co. seismograph party. Wildcat drilling on the Bethel dome was continued into 1929; four wells drilled by the Pure Oil Co. jointly with the Humble Oil & Refining Co. and the Gulf Production Co. have been abandoned.

Bullard (*Salt Dome*).—Wildcat drilling on the Bullard dome was continued into 1929. Four wells have been drilled to date by the Gulf Production Co. without encountering production. This interior salt dome is in the southern part of Smith County, Texas, 2 miles northeast of the town of Bullard. The dome was discovered in 1927 by a Gulf Production Co. seismograph party. There is practically no Woodbine sand logged in the wells and no showings of oil or gas were reported.

Hainesville (*Salt Dome*).—The Hainesville dome is in Wood County, Texas, 5 miles northeast of Mineola and south of Hainesville. Its existence was confirmed in 1927 by a Gulf Production Co. seismograph party. Only one test has been drilled; it encountered salt at 1228 ft. without showings of oil or gas. This well was abandoned in salt at a total depth of 1261 ft.

Sand Flat.—Sand Flat structure is in northern Smith County, 10 miles north of Tyler, the county seat. It was discovered, blocked, and drilled by the Amerada Petroleum Corpn., Christian No. 1 in the Felix Flores survey being the first and only test drilled to date. Sand Flat is an anticline just east of the axis of the East Texas geosyncline. It was discovered by surface work and later checked by seismograph exploration. Christian No. 1, on the north flank of the structure near the apex, penetrated good bodies of Nacatoch and Woodbine (Bingen) sands. Slight showings of oil were reported at depths between 4700 and 4800 ft. when the rotary samples were tested with ether. The top of the Woodbine (Bingen) sand was encountered at 4720 ft.; the red shales of Woodbine age were reached at 5025 ft. and the well was abandoned at 5400 ft. in gray sand.

Kelsey.—Kelsey structure is in the west central part of Upshur County, 6 miles west of Gilmer, the county seat, near the town of Kelsey in the J. H. Field survey. It was mapped and leased in the summer of 1928 by the Amerada Petroleum Corpn.

Kelsey is a large anticline, indicated on the surface by an inlier of Wilcox (Eocene) surrounded by younger Claiborne formations. Subsequent to the discovery of the surface structure, the Amerada Petroleum Corpn. checked the dome with seismograph. Wade No. 1, the first and only test drilled to date, was commenced in March, 1929, and abandoned in October at a total depth of 6153 ft., probably in the Glenrose (Lower Cretaceous). This well is near the apex of the dome.

La Rue.—The La Rue structure is in the eastern part of Henderson County, 13 miles southeast of Athens, the county seat, near the village of La Rue. It was discovered in 1927 by a Roxana Petroleum Corpn. seismograph party. Surface expression of the structure is somewhat vague, but some think that it is a deeply buried salt dome. Further exploration work by core drilling is being done at the present by the Shell Petroleum Corporation.

Blackfoot.—The Blackfoot structure is in the northwestern part of Anderson County, 18 miles northwest of Palestine, the county seat, and near the village of Blackfoot. It is approximately 6 miles northeast of the Bethel salt dome. This structure was discovered by surface geological work of the Humble Oil & Refining Co. Reklaw beds (Lower Claiborne) are exposed on the crest of the structure at a considerable distance east of the normal outcrop, indicating uplift. The structure is also complicated by faulting. The structure has not been tested.

Other Structures.—Many other structures have been reported in East Texas in the last months of 1929 but they have not been confirmed. Subsequent to the Van discovery, a gigantic leasing campaign was launched along a trend northeast and southwest from the Van structure, including parts of Freestone, Anderson, Henderson, Van Zandt and

Wood counties. As a result of the innumerable blocks of acreage assembled, some of which entail drilling contracts, many wildcat wells will be started within the next year.

Prospects Discovered during 1929

Leon County.—Early in 1929, the Sun Oil Co. discovered what is believed to be another salt dome, 3½ miles northwest of Marquez, in the northwestern part of Leon County. The dome is indicated on the surface by a circular black prairie, in a characteristically wooded, sandy region. The Navarro formation, Upper Cretaceous, is reported to outcrop on top of the dome, surrounded by Midway and Wilcox (Eocene) beds. Seismograph detail work is to be done by the Sun Oil Co. on the prospect early in 1930.

Development Along the Balcones Fault Zone

Fields Discovered during 1929

Darst Creek.—The most important discovery of the year along the Balcones fault zone is the Darst Creek field. It is in north-central Guadalupe County, in the Jacob C. Darst survey, 6 miles southwest from the Salt Flat (Bruner) field. The discovery was made on July 18, when Dallas Wilson No. 1 of the Texas Co. produced 1200 bbl. Oil was reported in the Austin chalk before production was discovered from the Edwards limestone (Lower Cretaceous), which is the principal producing horizon. Most of the acreage in the field is owned by a few of the major oil companies, therefore development has been slow while overtures for a proration program have been made to curtail production. Credit for the discovery goes to Dilworth Hager, geologist.

Darst Creek resembles Salt Flats and Luling long, narrow fields along the trace of faults. The oil in these fault-line fields is practically the same gravity and is found at about the same depth. The top of the Edwards is 2605 ft. in the discovery well. The initial production of the best wells in the Darst Creek field is approximately 2000 bbl.

At the close of the year, there were 12 producing wells in the field, with a total daily average production of 11,350 bbl.; six dry holes have been drilled. The productive area thus far extends over a distance of 6½ miles and is northeast of the discovery well. Over 30 wells were drilling at the close of the year, with the limits of the field still undefined.

Mount Calm.—On June 21, 1929, Harper & Latson's wildcat, Jones No. 1, in the A. C. Graves survey, in the southeastern part of Hill County, ½ mile west of Mount Calm, produced 125 bbl. of 31.3° gravity oil on the pump from the Austin chalk between 680 and 688 ft. Since several offset wells were subsequently drilled and missed production, the area has not fulfilled early promises. Numerous wells were drilled to the Woodbine sand, in which salt water was encountered without shows of

oil. At the close of the year, there were only three small wells in the pool, all producing from the Austin, with a total daily yield of only 38 barrels.

Fields Discovered Previous to 1929

Production from Lower Cretaceous (Edwards Limestone).—The outstanding development along the Balcones fault zone during 1929 was the Salt Flats (Bruner) field, which is in Caldwell County about 1½ miles north of the town of Luling. Previous to the discovery of production in the Edwards limestone, some oil had been produced from the Austin chalk. The field became prominent, however, when Edwards production was found by the Sun Oil Co.'s Malone No. 1, in October, 1928. It is the second Edwards limestone field on the fault line.

Much of the productive acreage is split into small holdings, rendering a curtailment program impossible. The field was rapidly developed, because only 10 days were required to drill a well from spudding to completion. Production reached its peak in June, 1929, when 245 flowing and pumping wells produced 1,495,740 bbl., or an average of 49,858 bbl. daily. A comparatively uniform decline occurred during the latter half of the year. The daily average production at the close of 1929 was 27,710 bbl. from 397 wells.

Very little drilling was done in the Luling field, and it had a steady decline. The total daily average production at the close of the year was 9390 bbl. from 583 wells.

Production from Upper Cretaceous (Woodbine Sand).—There has been practically no drilling during 1929 within the Woodbine sand fields along the Mexia-Powell fault zone; consequently production has steadily declined. Table 1 gives the comparative production in the fields for 1928 and 1929, classified according to the producing horizon.

Production from Upper Cretaceous (Navarro, Taylor, Austin).—Although most production in the Salt Flats (Bruner) field comes from the Edwards limestone (Lower Cretaceous), some oil is still being produced from the Austin chalk, at about 2300 feet.

Another upset of the year is recorded in the history of Norwood No. 1, of the Empire Gas & Fuel Co., which is near Ottine, in the northern part of Gonzales County, near the Caldwell County line. This well came in for 500 bbl., from a depth of 3790 ft., in the upper part of the Austin chalk. Since production declined after a short time to 100 bbl. per day by pumping, it was deepened in the hope of obtaining oil in the Edwards limestone, but salt water was found, and the well was plugged and abandoned at 4269 ft. Although offsets were drilled in every direction from Norwood No. 1, none found oil and the area was a disappointment. Nearly a duplication of the record of this well was experienced later in Manford No. 1, of Simms Oil Co. and Penn Oil

TABLE 1.—*Production in Fault-line Fields,* 1928 *and* 1929

Field	County	1928, Bbl.	1929, Bbl.
Woodbine Sand			
Powell	Navarro	3,968,655	2,776,615
Mexia	Limestone	2,517,744	1,908,247
Wortham	Limestone, Navarro, Freestone	647,572	410,810
Richland-Currie	Navarro	394,741	289,721
Nigger Creek	Limestone	221,850	119,043
Cedar Creek	Limestone	147,468	40,832
Boggy Creek	Cherokee	320,006	1,135,586
* Minerva-Rockdale	Milam	310,314	235,893
Edwards Limestone and Serpentine			
Salt Flats (Bruner)	Caldwell	392,320	13,539,624
Luling	Caldwell-Guadalupe	5,023,748	4,106,808
Darst Creek	Guadalupe		260,643
Lytton Springs†	Caldwell	477,610	350,478
Dale†	Caldwell	325,812	172,393
Yost†	Bastrop	10,252	478,214

* Nacotoch? (Navarro).
† Serpentine.

Co., southwest of the city of Luling, in the north end of Darst Creek field, both wells producing from crevices along faulting.

Very little new drilling has been done in the Somerset field, the only well of importance being a test of the Edwards limestone. Decline is slow in this old field, which has been producing for 15 years from the Navarro and Taylor formations of the Upper Cretaceous. The daily average production was 1746 bbl. at the close of the year.

An interesting bit of development in the old Minerva-Rockdale pool, which has produced over 3,000,000 bbl. of oil from the Navarro formation (Upper Cretaceous), is a deep test to the Edwards limestone (Lower Cretaceous)—the first deep test to be drilled in the shallow pool. Milton Phillips No. 1, of Texas Petroleum Development Co., in the J. J. Chambers survey, in the center of the pool, 600 ft. north of No. 14 abandoned, was dry and abandoned at 3711 feet.

Production from Serpentine.—No important development occurred in the Yost pool, located in Bastrop County, 5½ miles northeast of the Lytton Springs field. Production reached only about 3000 bbl. daily. Gravity of the oil is between 25° and 27°. The total daily average production at the close of the year was 773 bbl. from 22 producing wells.

The Dale area was extended in August, when Buchanan found another productive serpentine spot 2½ miles southwest of the Dale field. Buchanan's well found the serpentine at 1740 ft., and at 1764 ft. produced 50 bbl. in 12 hr. Later the well was deepened to 2050 ft. and was still in serpentine. Texas Company's Cude No. 1 found the serpentine at 1824 ft. and at 1836 ft. it blew out. This was the second producer in the pool. At the end of the year there were but four wells in the entire Buchanan pool. The total daily average production for Dale-Buchanan at the close of the year was 626 bbl. from 40 producing wells.

Very little development was done in the Lytton Springs field and production steadily declined. The total daily average at the end of the year was 872 bbl. from 28 producing wells.

Development during 1929 *for Trinity Sand* (*Lower Cretaceous*) *Production*

Mexia.—Deep drilling for Trinity sand production in the old Mexia field was continued into 1929. Trinity Oil & Gas Co.'s Thompson No. 5, approximately 1000 ft. west of the Mexia field, was abandoned in the late summer. Trinity sand is reported from 5711 ft. to the bottom of the hole, which is about 6060 ft. There were showings of oil at 5600 ft. in the base of the Glenrose (Lower Cretaceous), and also in the lower section of the part of the Trinity that was penetrated.

Kelsey (*Upshur County*).—When the Woodbine sand was found to be dry in the initial test, Wade No. 1, on the Kelsey structure, the Amerada Petroleum Corpn. determined to carry the well to the Trinity sand. It was abandoned, however, in October, 1929, at a depth of 6153 ft. without reaching the basement sands of the Trinity. The Paluxy sand (Lower Cretaceous), however, was encountered at 4967 ft. but it had no showings of oil or gas.

DISCUSSION

C. P. Watson,* Forth Worth, Texas.—This paper by Mr. Poulsen reviews what apparently is destined to be one of the most important producing districts of the United States. The commercial significance of this area, the fact that it is within 200 miles of tidewater, and the high-gravity oil encountered in the Van field at a depth of 2500 ft., are all contributing factors. The geologists contend that the normal depth of the Woodbine sand in that immediate area should be about 5000 ft., thereby indicating an uplift of 2500 ft. The sand has a thickness of more than 200 ft., according to actual penetrations that have been made. The extent of the field is 5000 acres, and estimates of recovery are between 50,000 and 75,000 bbl. per acre. This is probably destined to be an extremely important producing field of the United States.

* President, Federal Royalties Co., Inc.

Petroleum Development in North Central and West Central Texas during 1929

By J. Whitney Lewis,* Fort Worth, Texas

(New York Meeting, February, 1930)

This review covers that portion of the area between the Llano mountains and the Red River which lies between Fort Worth and Abilene. The counties and fields included are listed in Tables 1 and 2. During 1929 there was a marked lull in both prospecting and development in this part of Texas. Archer, Coleman, Cooke, Wilbarger and Young were the counties most active.

The total gross production of the year was 52,611,000 bbl., 3 per cent. more than for 1928. The production of the Coleman, Cooke-

Table 1.—*New Wells in North and West Central Texas with Initial Capacity of* 50 *bbl. or more*, 1929

Discoveries	Initial Daily Production, Bbl.	Discoveries	Initial Daily Production, Bbl.
Archer County:		H. C. Shanafelt No. 1...	75
H. Horrey No. 1.........	60	Palo Pinto County:	
W. H. Taylor No. 1......	180	J. B. Hart No. 2.........	50
A. D. Thompson No. 1...	100	Shackelford County:	
J. M. Bloodworth No. 1..	60	W. I. Cook 2-A..........	275
L. F. Wilson No. 1.......	150	Throckmorton County:	
Callahan County:		R. M. Titus No. 1-B.....	60
Maggie Alexander No. 1..	100	Wilbarger County:	
		W. T. Waggoner No. 1...	110
N. Jackson No. 1........	184	Waggoner No. 1.........	425
		Young County:	
Cooke County:			
Timmis 6-B...........	4320	W. H. Corbett No. 1.....	400
J. F. Huggins No. 1......	220	R. Morrison No. 1.......	115
Eastland County:		Mizzell-Perkins No. 1.....	200
Maggie Gray No. 1.......	850	Seddon No. 1...........	180
Mrs. J. E. Kincade No. 1..	150	E. F. Brown No. 1.......	55
Foard County:		J. Kissinger No. 1........	85
W. S. Tarver No. 1.......	228	N. Burch No. 1..........	200
Jack County:		J. K. Thomas No. 1......	70
Boyd No. 1.............	118	G. P. Stewart 1-B.......	30

* Consulting Geologist.

TABLE 2.—*Completions and Production in North Central and West Central Texas*, 1929

County or Field	Completions	Producers	Gas Wells	Failures	Initial Production, Bbl.	Production 1929, Bbl.	Production 1928, Bbl.
Archer	606	274		332	14,600	6,668,000	7,402,550
Baylor	5			5			
Brown	418	203	12	203	22,985	3,260,000	4,503,300
Burkeburnett	43	32		11	467	3,292,000	3,992,500
Callahan	127	43	2	82	1,512	1,366,000	1,363,450
Clay	53	27	4	22	846		
Coleman	288	124	26	138	28,920	1,913,000	978,950
Comanche	10	4	1	5	105		
Cooke-Montague	211	137	3	71	23,370	5,045,000	4,254,550
Eastland-Desdemona	175	56	17	102	4,539	2,471,000	2,781,950
Electra	187	100		87	5,340	4,518,000	4,607,600
Erath	29		21	8			
Fisher	1	1			300	214,000	197,532
Foard	11	7		4	665		
Grayson	13		5	8			
Haskell	19	6		13	315		
Hood	2			2			
Jack	20	11	1	8	1,480	822,000	540,150
Jones						700,000	934,864
K.M.A. Iowa Park	327	230		97	13,713	1,854,000	1,180,050
Knox	2			2			
Mills	1			1			
Palo Pinto	43	11	14	18	450	154,000	160,400
Parker	2			2			
Shackelford	309	135	4	170	11,000	4,300,000	3,433,850
Stephens	84	25	15	44	968	2,318,000	2,750,650
Throckmorton	31	11	5	15	200	242,000	343,900
Wilbarger	534	411		132	55,876	10,458,000	8,004,950
Young	466	210		256	12,800	2,716,000	3,062,400
All others	100	50		50	15,000	300,000	455,150
Total	4,117	2,108	130	1,888	215,451	52,611,000	50,948,746

Montague, Jack, K. M. A., Iowa Park, Shackelford and Wilbarger districts was responsible for the increase. The other districts showed a decline, though successful repressuring in many pools materially aided in maintaining production. There were 4126 completions of which 2108 were producers, 130 gas wells and 1888 failures. The average initial production was 50 barrels.

Most of the discovery wells drilled in the area during the year are given in Table 1. The outstanding features were the discovery of several important pools and extensions in Coleman County and the development of a pool in the bend in Cooke County.

Archer County contributed nine discoveries with average initial productions of 50 bbl. The sands were of Cisco age and were reached at depths of from 1100 to 1600 ft. A total of 606 wells were drilled of which 274 produced. The total production was 6,668,000 bbl., slightly less than that of the preceding year.

In Brown County repressuring in the Blake and Fry pools proved successful. Several extensions in the Cross-cut and Fry areas brought the production to above 10,000 bbl. daily. The total production for the year was 3,260,000 bbl., approximately 30 per cent. less than that of 1928. Important gas reserves were also developed in the southern part of the county.

In Callahan County a new pool was discovered north of Baird, in a Cisco sand at 1000 ft. The initial production was 200 bbl. The daily production of the county averaged 3500 barrels.

Coleman County produced 1,913,000 bbl. in 1929, a 100 per cent. increase over 1928. In December the daily production was 8500 bbl. The outstanding development included a northward extension of the Burkett pool where some 150 wells are producing from a sand at 390 ft., the discovery of a new pool 12 miles south of Coleman where a 200-bbl. well was encountered in a sand at 684 ft., and three discoveries of Canyon sand production in the southwestern part of the county.

Most of the marked increase in daily production was furnished by the Fry sand wells in the Eastland pool, seven miles northeast of Coleman and the Overall pool eight miles southwest of Coleman. Three wells with initial productions of greater than 2000 bbl. each were completed in the former. Recoveries in these two pools have already passed 6000 bbl. per acre with indications of 14,000 bbl. ultimate recoveries. There have been several large gas wells in the Eastland pool, and another, the Texas American Syndicate Newton No. 2 in the northwest corner of the county. This last mentioned well developed 15,000,000 cu. ft. at 3800 feet.

There are now 12 distinct producing horizons in the county, and the entire district is undergoing a continuous prospecting. A continued increase in production in the proven areas is to be expected during the coming year.

In Cooke County interest is centering on the development of oil in the pre-Pennsylvanian near Muenster. The best well in this horizon had an initial production of 4320 bbl. at a depth of 1466 ft. The total production of the Cooke-Montague district showed a 20 per cent. increase over that of 1928.

Comanche County is attracting interest because of a contemplated test of the pre-Mississippian, which is being handled as a joint venture by the Sun Company for 10 participants. The block consists of 33,000 acres situated near Comanche City.

In Eastland County the discovery north of Cisco may prove an important pool in the Bend at 3456 ft. and the development of a pool at 1000 ft. near Carbon were the only important developments.

Shackelford County contributed a third Cook Ranch pool. Most of the production of the county continued to come from the original Cook pool and the immediate vicinity where unit repressuring has been practiced from the first. The year's production was 4,300,000 bbl., an increase of 866,150 bbl. over 1928.

Wilbarger County produced 10,458,000 bbl. in 1929, an increase of 30 per cent. over 1928. During the year there were 543 completions including 411 producers. It should be noted that the Chamber of Commerce of Wichita Falls is raising a fund for drilling six wells to 6000 ft. in North Texas.

The Chamber of Commerce of Breckenridge is promoting a deep test in Stephens County, and everywhere there appears a growing interest in the possibilities of the pre-Mississippian formations.

Young County was the scene of considerable successful prospecting. There were 12 discoveries ranging in depth from 557 to 4250 ft. The Bryson area was particularly active. The year's production was 2,716,000 bbl., being slightly less than that of 1928.

Petroleum Development in Southwest Texas during 1929

By Olin G. Bell,* Laredo, Texas

(New York Meeting, February, 1930)

While all of the Southwest Texas fields lie within the Gulf Coastal Plain this area may be divided into three subdivisions—the Coastal Plain zone proper, the Reynosa Escarpment zone, and the interior zone. The Coastal zone includes that strip adjacent to the Gulf of Mexico and extending inland for a distance of about 60 miles and includes the Palo Blanco, Palangana, Piedras Pintas, Kingsville, Agua Dulce, Saxet, White Point and Refugio fields. The Reynosa Escarpment zone includes a Pliocene overlap over older Tertiary sediments lying west of the Coastal zone. The western margin of the Reynosa formation forms a more or less well-defined westward facing escarpment with which the so-called Reynosa Escarpment fields are indirectly related. These fields include those in eastern Zapata, eastern Webb, western Jim Hogg, western Duval, McMullen, Live Oak, Bee, Goliad and Victoria counties. The interior zone includes these fields west of the Reynosa Escarpment which are not in any way related to it and are on separate types of structure.

Production data by fields and wells are shown in Table 1.

Roma.—During 1928 the Texas Co. completed two small gas wells at 198 ft. on the Roma Structure near the town of Roma on the Rio Grande in Starr County. This gas is of no commercial importance but was used for fuel in drilling other deep tests on this structure. Three dry holes ranging from 3600 to 4200 ft. were drilled; then their No. 4 Guerra, the fourth deep test, was completed during December as a small producer of 37° Bé. oil from a sand at 3560 to 3590 ft. No production was marketed during December but arrangements were being made to handle the output from this well during 1930. This is the first commercial producer in Starr County.

Driscoll.—In 1929, Robert Driscoll discovered gas on his Santa Rosalia Ranch in Duval County while drilling water wells. Two sands were developed, one at 2400 ft. and another at 2936 ft. and several gas wells were completed in each, ranging in volume from 15,000,000 to 40,000,000 cu. ft. and in reservoir pressure from 500 to 1,000 lb. Early in January of 1929, Mr. Driscoll's No. 14 Fee was completed as a 50-bbl. oil producer at 2894 ft. Two other oil producers were completed early in 1929. Mr. Driscoll's death early in the year curtailed develop-

* Division Geologist, Humble Oil & Refining Co.

ment in this area during the remainder of the year. This field produced 66,555 bbl. from two wells during the year.

Escobas.—During December of this year Harry L. Fansler completed his No. 1 Cuellar in Survey 285 on the Escobas Ranch 5 miles south of the Cuellar field in Zapata County as a 30,000,000-cu. ft. gas well with a reservoir pressure of 700 lb. in a sand from 1664 to 1668 ft. This well very probably opens a new pool in this part of Zapata County. There

NEW POOLS

TABLE 1.—*Summary of Southwest Texas, Petroleum Fields,* 1929

Field	Production, 1929, Bbl.	Total Production since Discovery, Bbl.	Daily Production, Dec. 31, 1929, Bbl.	Number of Producing Wells, Dec. 31, 1929, Bbl.	Daily Average Production per Well Dec. 31, 1929, Bbl.	Number of Producing Wells Abandoned during 1929
Albercas	943,494	1,656,185	1,169	80	14.6	18
Aviator	447,798	3,632,735	1,042	157	6.6	105
Carolina-Texas	31,351	64,000	52	7	7.4	0
Cole-Bruni	638,866	1,198,706	1,042	51	20.4	0
Charco Redondo	42,115	84,497	118	121	0.9	0
Cuellar	201,890	231,993	1,498	25	59.9	0
Driscoll	66,555	66,555	204	2	104.0	0
Government Wells	550,933	586,572	1,908	48	39.7	0
Henne-Winch-Fariss	37,455	2,838,643	178	59	3.0	83
Kingsville	117,150	472,560	250	9	27.7	3
Kohler	38,806	69,289	238	13	18.3	0
Mirando Valley	27,058	395,797	62	17	3.6	7
Mid-Ojuelos	224,844	2,086,747	242	52	4.6	50
Palangana	350	2,223	None	None		1
Randado (including Alworth)	482,909	2,900,502	1,013	139	7.3	22
Refugio	2,106,055	2,176,647	17,592	78	225.0	0
Schott-Mirando City	289,820	4,286,150	618	112	5.5	46
Wolcott	33,647	485,785	91	20	4.5	6
Total	6,281,096	23,235,586	27,317	990		341

were, however, four other wells drilled in this area earlier in the year, one of which showed some oil and another some gas.

Palo Blanco.—The Houston Oil Co. completed its No. 1 Lassiter in the Palo Blanco area of northwestern Brooks County in September as a gas well 4110 ft. having a volume of 40,000,000 cu. ft. and a reservoir pressure of 1600 lb. This structure was worked out by geophysical methods and the first test drilled was the discovery well. One additional test was being drilled at the close of 1929.

Pettus.—Early in the year Dr. H. E. Hewitt encountered about 2,000,000 cu. ft. of gas with 1100 lb. reservoir pressure in a 2600-ft.

sand in his No. 1 Ray near Pettus in northeastern Bee County. This well later went to salt water. The Moody-Seagraves interests took over the Hewitt tract during the year and in May drilled their No. 2 Ray nearby which was completed as a 30,000,000-cu. ft. gas well with 800 lb. reservoir pressure in a sand from 2830 to 2902 ft. This was the first commercial producer in Bee County. Their No. 3 Ray was drilled just across the line in Goliad County and was completed as a small gas well making about 15 bbl. of oil per day from a sand from 4054 to 4062 ft. Their No. 4 Ray was a dry hole and two additional wells were drilling at the close of the year.

At the close of December the Humble Oil & Refining Co. was completing an oil well drilled by the Houston Oil Co. in this immediate area. The sand is from 3957 to 3971 ft. and the oil has a gravity of 42° Bé. This will probably prove to be an important producing area in Bee County. It is not far distant from the Goliad producing area and possibly is on a similar type of structure.

Goliad.—F. P. Zoch completed his No. 1 Kaufman about 12 miles west of Goliad in Goliad County in December as a 25,000,000-cu. ft. gas producer with 1600 lb. reservoir pressure from a sand at 4216 to 4230 ft. This well probably marks the discovery of a new producing area in northwestern Goliad County and is possibly similar to the Pettus area in Bee County.

Old Fields

During the year two deep holes were drilled at Randado, one 5200 ft. and one 3180 ft., in an effort to find lower pay horizons in this field.

The Refugio field has been by far the most active in this area during the year. It produces gas and oil from a 5200-ft. and a 3700-ft. sand as well as gas from several shallower sands. There were four producing oil wells at the beginning of the year and at the close there were 76 producing gas wells and 22 dry holes within the field. There were 42 wells drilling Dec. 31.

At Kingsville, the Humble Oil & Refining Co. drilled one well, No. 4 Flato, to 6922 ft. Several shows of both oil and gas were encountered but no commercial production was found. This is the deepest well so far drilled in Southwest Texas. One other dry hole and one gas well was drilled during the year.

While there was active wildcatting in Maverick County during the year there was no important production developed. The Rycade has continued its exploratory work on the Chittem Ranch with two wells drilling below 5000 ft. Its No. 5 Chittem produced a total of 1500 bbl. from the Eagle Ford, then went dry and is being deepened.

The Albercas field opened early in 1928 and reached its peak before the beginning of 1929. During the year there were only 10 new producing wells drilled and four dry holes.

The Government Wells pool was developed in a normal manner with 40 new oil wells, six new wells and four dry holes.

The Agua Dulce gas field had five new gas wells drilled, making a total of nine producers and several dry holes in the surrounding area. Late in the year the Moody-Seagraves interests completed an 8-in. gas line outlet from this field which will stimulate activity.

The old Jennings gas field and the Cuellar field, its southeastward extension which was opened late in 1928, were the center of some extended exploration and development. In the Cuellar field there were 20 oil wells, six gas wells and seven dry holes completed. In the Jennings field there were two new gas wells and three dry holes drilled.

The Henne-Winch-Fariss field was rapidly declining during 1929, with but two new oil producers, two gas wells and four dry holes.

The Carolina-Texas field has yielded two new oil wells, three gas wells and four dry holes.

In the Cole-Bruni field 30 new gas wells, six new oil wells and eight dry holes were drilled.

The Dinn gas pool is in reality a northward extension of the eastern Cole-Bruni field. Development was resumed in 1929 and 10 new gas wells were completed.

The Schott-Mirando City, Mid-Ojuelos, Wolcott, Aviator and Mirando Valley fields comprising the original Reynosa Escarpment fields, reached their maximum development in 1927, and no new wells of importance were drilled in these pools during the year.

The Simmons City, Three Rivers, Crowther, Grubstake and Calliham fields form a series of shallow oil and gas fields of minor importance, with practically no activity during 1929.

The Mount Lucas, Mathis and Worth gas fields were fairly quiet during the year. At the close of the year the Houston Oil Co. was drilling at 4000 ft. on a deep test in the Mount Lucas field. The producing horizons in these fields range from 1400 to 2100 feet.

Palangana and Piedras Pintas, two old salt domes, were very quiet. One dry hole was drilled at Piedras Pintas. Some cap rock production was developed at Palangana during 1928 and continued in 1929. The Duval County Sulfur Co. is developing the sulfur resources at Palangana.

In the White Point gas field, at the close of the year, there were 33 producing gas wells in White Point and 12 in Saxet. The F. P. Zoch No. 1 Baldwin drilled early in the year marked a 2-mile extension southward from the Saxet field.

At Nursery, the Humble Oil & Refining Co. began drilling a deep test which, at the close of the year was below 5000 feet.

In the Kohler pool one new oil well was completed in the 2800-ft. sand, 14 gas wells and eight oil wells were completed in the 1800-ft. sand and 10 dry holes.

Three dry holes were drilled in the old Reiser field, an abandoned gas field.

The Charco Redondo field, a shallow pool, productive horizon 170 ft., was very quiet. At the close of December there were 121 wells producing 118 bbl. daily.

The Leaseholders field, at one time a small and unimportant oil producer, was inactive during the year.

The Alworth pool in western Jim Hogg County is a small and unimportant field producing from a 1000-ft. sand. During the year one 25-bbl. well and one dry hole were drilled.

Wildcat Drilling

In Goliad County several wells were drilled in the northwestern part of the county. The Humble Oil & Refining Co. was engaged in core drilling a large block of acreage in the northeast part of the county.

In Brooks County, Amos Dinn and W. R. French have each drilled several shallow structure tests. Some of these French holes have been in Hidalgo and Starr counties. The Humble Oil & Refining Co. started a deep test late in December on the Alta Verde prospect in west central Brooks County. This area was first worked by the seismograph.

In Dimmitt County the Texas Fall Gas Co. has drilled several tests down to about 1500 feet.

In Live Oak County a number of tests have been drilled, some of which have gone below 4000 feet.

The John Pappas Nos. 1 and 2 Cuellar, near Zapata in Zapata County, showed some gas at 1400 ft. but failed to make wells.

Petroleum Developments in Texas Panhandle in 1929*

By William E. Hubbard,† Amarillo, Texas

(New York Meeting, February, 1930)

The Panhandle area of northwest Texas embraces the northern portion of the Permian Basin of Texas as well as a considerable portion of the western part of the Anadarko Basin of Oklahoma. For the purpose of this report it will include in addition to the 20 counties of the Panhandle proper the two tiers of counties lying to the south, a total area of about 32,000 square miles.

Crossing the Texas Panhandle diagonally from northwest to southeast is the Amarillo Arch, related to which is all of the production discovered to date.

Oil Production

Up to Jan. 1, 1930, the Panhandle has produced about 125,000,000 bbl. of oil. The peak yearly production occurred in 1927, during which period 49,000,000 bbl. were produced. In 1928 the production fell to 25,000,000 bbl., but in 1929, on account of important discoveries in Gray County, the total increased to 31,000,000 bbl. To date Hutchinson County has produced 64 per cent. of the total. Table 1 shows the total yearly production by counties.

Table 1.—*Panhandle Gross Production**

Year	Carson, Bbl.	Gray, Bbl.	Hutchinson, Bbl.	Moore, Bbl.	Potter, Bbl.	Wheeler, Bbl.	Total, Bbl.
Before 1926	1,029,200	17,400	454,800		4,000	27,300	1,528,700
1926	1,076,800	1,272,600	23,521,400		7,600	106,900	26,009,300
1927	3,280,500	4,143,300	32,881,400	11,900	12,000	698,400	41,009,500
1928	2,445,200	7,846,900	13,878,100	287,800	9,000	362,800	24,837,800
1929	2,860,200	18,563,700	8,913,400	509,200	5,100	254,000	31,105,600
Total....	10,691,900	31,843,900	79,659,100	808,900	37,700	1,459,400	124,480,900

* Figures were taken largely from weekly production reports and should closely check pipe line runs.

The present production of the Panhandle is 100,500 bbl. from 1745 wells or an average of 57.6 bbl. per well compared to a production on Jan. 1, 1929, of 59,748 bbl. from 1468 wells or an average of 40.7 bbl. per well. The peak production of the year occurred during the week

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† Division Superintendent, Humble Oil & Refining Co.

ending Aug. 29, when a daily average of 137,365 bbl. was produced from 1636 wells or 84 bbl. per well. The average daily production for the year was 85,200 bbl. from an average of 1690 wells or 50.4 bbl. per well.

Due to shutdown agreements and proration Gray County production has dropped from a peak of 100,365 bbl. during the week ending Aug. 29 to 64,173 bbl. as of Jan. 1. There is little question that Gray County production would have been maintained at somewhere near its peak had curtailment not been effected.

The total initial production of Panhandle wells drilled in 1929 was 257,700 bbl. from 350 wells or 734 bbl. per well as compared to 64,650 bbl. from 185 wells or 290 bbl. per well for the year 1928.

Gray County completed oil wells had an average initial production for 1929 of 988 bbl. or a total of 230,000 bbl. from 233 wells.

Completions

During 1929, 503 wells were completed in the Panhandle as compared with 357 completions in 1928. Of the 1929 completions 350 were oil wells, 111 were gas wells and 42 were dry holes.

A total of 2501 wells have been drilled in the Panhandle to date, of which 1939 were oil wells, 364 were gas producers and 198 were dry holes, making the ratio of dry holes to producers about 1:11.6.

As 53 of the 198 dry holes were drilled in nonproducing counties the ratio of dry holes to producers in the productive counties has been very favorable indeed; *i. e.*, about 1:15.9.

Fifty-six producing oil wells were plugged and abandoned in 1929, 49 of them in the lime-producing area of Hutchinson County where water encroachment has been extremely rapid. Eighteen producing oil wells were plugged for gas wells, seven of which were in Hutchinson County.

Gas Wells

There were 111 gas wells completed in the Panhandle during the year. Their open flow capacity was 2,926,000,000 cu. ft. or 26,400,000 cu. ft. per well as compared with 103 wells averaging 28,900,000 cu. ft. for 1928. The total number of gas wells completed in the Panhandle is 364; total yield, 10,235,000,000 cu. ft.; average yield per well, 28,100,000 cu. ft. Forty-four producing oil wells have been plugged back for gas and should average possibly 15,000,000 cu. ft. apiece.

Approximately 50 per cent. of the gas wells completed in 1929 were drilled in Wheeler County. No increase in the Panhandle gas area was effected by the year's development, the general estimate being in the neighborhood of 1,000,000 acres.

About 2 per cent. of the open flow capacity or approximately 200,000,-000 cu. ft. is being taken out of the area by pipe lines, the greater portion

of it going to Kansas and Colorado points. In addition to this, about one billion feet of gas is produced daily with the 100,000 bbl. of oil.

Casinghead Gas

Eleven casinghead gasoline plants were built during the year with a total capacity of 160,000,000 cu. ft. Seven of these were in Gray County, two in Carson, one in Wheeler and one in Potter. Three plants were abandoned in Hutchinson County. The total number of plants increased during the year from 44 to 52. There were 48 casinghead gasoline plants in operation as of Jan. 1, 1929, with a capacity of 991,000,000 cu. ft.; and four domestic gas line plants with a capacity of 132,500,000 cu. ft. of gas from gas wells.

The total casinghead gasoline production for 1929 was 203,000,000 gal. or 6.5 gal. per bbl. of oil produced. The present daily production of casinghead gasoline is about 850,000 gal. or 52 per cent. higher than the average for 1928.

Carbon Black

Eight carbon plants with a total capacity of 200,000,000 cu. ft. of gas were completed in 1929 as against 10 plants with a capacity of 177,000,000 cu. ft. in 1928. The number of plants now in operation is 23 with a total daily capacity of 447,000,000 cu. ft. The present output of carbon black is at the rate of about 120,000 tons per year, most of which is utilized by the tire industry.

Drilling

Of the 503 wells drilled in the Panhandle in 1929 about two-thirds were drilled with cable tools. In Gray County, however, there were 169 drilled with rotary and 129 with tools. In the eastern half of Gray County and all of Wheeler County it is generally conceded that tools are the more satisfactory while rotaries are more generally used in the western portion of Gray County.

Drilling costs, outside of Wheeler County, average around $30,000, while pumping and lease equipment will amount to about $7,500 per well. Production costs on wells of the average size drilled to date should not be over 30 c. per bbl. The economic limit of production has been variously estimated at from 3.5 to 10 bbl. per well, depending upon water troubles, number of wells per lease, etc., which should give the average well a productive life of about 5 years.

Curtailment Program

During the last four months of the year it was found necessary to curtail both new development and existing production in Gray County because of lack of pipe line outlet. At the close of the year a prora-

tion agreement was effected among the operators in the rather prolific Bowers and Finley pools patterned somewhat after the well known Winkler County Plan.

New Developments in 1929

Carson County.—In the stubblefield area, along the Hutchinson County line in northeast Carson County, about 40 wells were completed for an average initial production of 225 bbl., the largest being 445 bbl. This production is from a sandy-lime horizon near the base of the Big Lime, and correlates roughly with the pay zone north of the Canadian River in Hutchinson County. The small initial production of these wells is undoubtedly due to lack of gas as their decline is apparently sufficiently slow to allow of an ultimate production equal to that of an average well twice as large.

Hutchinson County.—In the latter part of May a rather promising area was opened up by the Continental No. 1-C Johnson in sec. 5, block 1, B & B Survey, 4½ miles west of the Borger pool. At this point the top of the Big Lime occurs at about 1400 ft., which is the highest contour at which production has yet been found in the Panhandle. Moreover, the situation is rendered still more unique by the fact that the production comes from a sandy phase 1300 ft. in the Big Lime. The general thickness of the Big Lime on this contour has previously been found to be from about 750 ft. in Carson County to practically nothing in parts of Potter County. Nowhere else has this horizon been productive as it has been water-bearing where penetrated farther down the flank of the arch.

Three wells have been completed to date in the immediate area with an average initial production of 1680 barrels.

The structural position at this point would lead one to believe that folding had taken place along the arch considerably after the period of oil accumulation.

Gray County.—The Marland Finley pool and the northeast extension to the Bowers pool in central Gray County were the high lights of 1929 development in the Panhandle.

The discovery well of the former area was the Marland No. 1 Finley, sec. 32, block B-2, H & GN Survey, which was completed on March 21 at 2400 bbl. from granite wash at 2843–45. Sixty wells have been completed in the pool with an average initial production of slightly over 2000 bbl. The largest completion was the Phillips No. 4 Palmer with an initial production of 20,700 bbl. Although drilling has been retarded to a minimum the field is far from being defined. The recent completion of the No. 10 Coombs & Worley of the Wilcox company 1 mile north of the pool as a 2000-bbl. well together with the structural conditions to

the south and east of the pool would indicate that the total productive area will, at a minimum, be three times that now producing.

In the northeast extension to the Bowers area 65 wells averaging 1500 bbl. were completed, the largest of which, the No. 13 Bowers of the Texas Co., made 12,000 bbl. initially.

Production from the Finley and Bowers areas should average between 20,000 and 25,000 bbl. per acre.

The Saunders area east of the town of Lefors, although its discovery dates back a couple of years, is worthy of mention because of the total for the year of 25 completions averaging about 800 barrels.

In eastern Gray County the Chapman area was extended 1½ miles to the northeast by the 1400-bbl. completion of the Scott Drilling Co. in the center of sec. 69, block 25. The pool furnished 17 completions averaging 431 bbl., 5 dry holes and two gas wells.

Little new light concerning the possibilities of good production on the south side of the granite ridge was afforded by the year's development.

Dillard et al. drilled a 50-bbl. pumper in southwest Gray County, sec. 202, block B-2, while the Holloway No. 1 of Stogner et al. in south central Gray County, sec. 7, block H, Wallace Survey, was a near-producer at 3053 to 3090 feet.

To date no commercial oil wells have been drilled that can be definitely placed on the south flank of the ridge although a few small wells and many shows have been encountered. Inasmuch as gas in commercial quantities is nearly always present, further testing for oil is decidedly warranted.

Production Outlook

Four years ago the Panhandle was generally looked upon as a vast reservoir of oil from which production could and would be withdrawn as the economic situation warranted. Since then little has happened to change this picture save that the average indicated ultimate production per oil well drilled has been revised upward from about 75,000 to 85,000 bbl., allowing oil to be produced profitably at a correspondingly lower market. Should present conditions either prevail or improve in the future there is scant reason why the area should not continue to produce at its present rate for the next 25 to 30 years.

Petroleum Developments in Gulf Coast of Texas and Louisiana during 1929

By R. H. Goodrich,* Houston, Texas

(New York Meeting, February, 1930)

Development in this district during the year 1929 was little different from that of any other year despite the somewhat depressed condition of the oil business in general. The year was marked by: (1) An intensive geophysical campaign in the search of deep-seated salt domes; (2) the rather successful exploration and development of lateral sand production on the flanks of some of the older domes.

Geophysical Exploration

Geophysical work is confined almost exclusively to the torsion balance and seismograph. At the beginning of the year there were approximately 185 individual instruments of all types engaged in the search of structures in the Gulf Coast of Texas and Louisiana. This total includes 3 magnetometers, 83 torsion balances and 100 seismographs. The number of parties operating the torsion balances was 47; seismographs, 20; magnetometers, 3. It is estimated that 4,800,000 lb. of dynamite or other explosives were used in seismic exploration.

During the year the torsion balance and seismograph were credited with having discovered the following salt domes: Texas, Danbury dome, Brazoria County, H. & T. B. R. Co., and Clodine dome, Fort Bend County, John Fredricks and Wm. Stanley, Satowsky Survey; Louisiana, Iowa dome, Calcasieu and Jefferson Davis Parishes, T. 9 S., R. 6 and 7 W., and Cameron-Meadow dome, Cameron Parish, T. 14 S., R. 13 W. Because of the secrecy maintained in these developments, it is somewhat hazardous to venture opinion as to the number of salt domes found during one year.

The discovery of gas at Mykawa district and at Genoa district, in Harris County, Texas, is considered of more than passing importance, because there is indication in the performance of these two districts that commercial accumulation of oil and gas may be found in the Gulf Coast on structures other than the more or less definite salt dome type. While it is generally conceded that the accompanying structure in these instances are deeply buried salt domes, it is a fact that neither the seismograph nor the drill have indicated the presence of salt.

* Consulting Geologist.

There are possibilities of locating and mapping, with the torsion balance, structures in the Gulf Coast that may not necessarily be of the positive salt dome type. In the case of Mykawa district, the Humble Oil & Refining Co. completed its W. H. Irvin No. 2, on Aug. 19, 1929, as a 50,000,000-cu. ft. gas well with rock pressure of 1500 lb. from a total depth of 4190 ft. There does not seem to be more than 400 ft. uplift of the middle fossiliferous Oligocene formation in this well and even less uplift in Woodburn No. 2 at Genoa district which tested 1300 lb. rock pressure in sand at 3406 to 3426 ft. This is to be compared to the deep-seated Sugarland salt dome where there is definitely as much as 1600 ft. uplift on the same formation and to some of the older shallow type salt domes where there is not less than 6000 ft. uplift on th Oligocene formation.

There have been other developments within the past two years in the Gulf Coast, such as at Needville, in Fort Bend County, Texas, and at Roanoke, in Jefferson Davis Parish, Louisiana, where the drilling has been rather unprofitable, nevertheless the nature of the formations encountered and the predominance of oil shows in these tests, definitely indicate structural conditions. These areas, of course, are easily explained as being deep-seated salt domes. It is suggested that such areas may represent structures not necessarily of the positive salt dome type.

TABLE 1.—*Discovery of Oil in* 1929 *on Salt Domes Found by Geophysical Methods*

Name	County or Parish	Depth, Ft.	Initial Production Bbl.	Gravity of Oil, Deg.
Texas:				
Lost Lake	Chambers	2748 to 2782	500	23
Genoa	Harris	3405 to 3425	gas	1300 R.P.
Mykawa	Harris	4150 to 4190	gas	1600 R.P.
Hankamer	Liberty	2632 to 2678	700	20
Esperson	Liberty	3305 to 3321	1000	24.5
Moss Bluff	Liberty	5502 to 5668	800	32
Port Neches	Orange	3140 to 3170	2000	21.5
Louisiana:				
Black Bayou	Cameron	950 to 980	50	19.5
White Castle	Iberville	5700 to 5837	100	21
Bayou Blue	Iberville	1910 to 1928	20	18.5
Port Barre	St. Landry	3728 to 3765	1000	23.5
Bay St. Elaine	Terrebonne	650 to 681	gas	
Dog Lake	Terrebonne	1055 to 1064	15	17.5
Lake Barre	Terrebonne	3840 to 3845	1500	27.5
Lake Pelto	Terrebonne	1251 to 1390	400	17

Production was developed in 1929 on the domes reported in Table 1. These domes are considered as having been found by geophysical methods.

Geological

The rather hectic geological activity in the Northern Boundary of the Gulf Coast district proper that developed in 1928 along the Reynosa-Lagarto contact and the Jackson-Catahoula contact has abated somewhat. Geological work along these contacts was started when the Clay Creek field, in Washington County, demonstrated that commercial production existed in the Cooks Mountain formation and when the Raccoon Bend field, in Austin County, demonstrated that commercial production was to be found in the Jackson formation.

The discovery of definite upper Cretaceous formation on one of the shallow salt domes in the Gulf Coast is an important contribution to those interested in salt dome genetrics. It affords rather definite proof that the source of the salt in the coastal region is as old or older than Cretaceous. A solid 35-ft. core section of marl of upper Cretaceous age was encountered from 2012 to 2057 ft. in the Navarro Oil Co. Community No. 4, on the Northeast side of the South Liberty salt dome. The predominance and definite character of foraminifera in the marl section from this well leaves no doubt as to the identity of the formation. It has been known for some years that Oligocene and Jackson are found overlying the cap rock of many of the coastal domes, but this is the first authentic record of Cretaceous having been found on top of any coastal salt dome. It is peculiar to note that the section of Cretaceous was located below the top of the limestone cap rock and above rock salt.[1]

In Victoria County, about 2 miles East of the town of Nursery, the Humble Oil & Refining Co. developed a shallow gas field in the Lagarto formation and are drilling a deep test which had considerable gas showing from a depth of 5700 ft. This does not seem to be a salt dome but possibly a broad flat top anticlinal structure. The surface indications, pointing to the likelihood of structure here, consisted of a series of quartzite outcrops within the Lissie formation; this same series of quartzite outcrops continue with interruptions to the Southwest through Goliad and Bee counties. Considerable drilling has taken place along this supposed line of weakness and a gas field has been developed at Pettus, in Bee County, and the Houston Oil Co. N. 1. McKinney gives promise of making an oil well.

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[1] T. E. Morrison: First Authentic Cretaceous Formation Found in Gulf Coast Salt Domes of Texas. *Bull.* Amer. Assn. Petr. Geol. (1929) **13**, No. 8, 1065.

Production and New Developments

Production in the Gulf Coast of Texas and Louisiana during the year exceeded that of any other year by only 3,000,000 bbl., in spite of the fact that there were developed, during the year, 14 new oil fields and new lateral sand production, and extensive development work was carried on around four of the older domes that were already producing. In 1929 many of the fields actually showed a marked decline in production, as shown in Table 2.

Table 2.—*Production Decline*

Field	Production, 1929, Bbl.	Production, 1928, Bbl.	Decline, Bbl.
Sour Lake	983,100	1,235,100	252,100
Spindletop	9,923,000	14,021,400	4,098,300
West Columbia	2,382,100	2,946,100	564,000
Orange	1,059,100	1,466,200	407,100
Hull	3,417,000	4,167,000	750,000
Blue Ridge	1,207,100	2,302,100	1,095,000

The decrease of nearly 4,000,000 bbl. in the production of Spindle top was adequately offset by the increase at Barbers Hill. The three following districts, Raccoon Bend, Refugio and Clay Creek, while not strictly belonging in the Gulf Coast, contributed 5,000,000 bbl. of new oil. The fields showing marked increases are indicated in Table 3.

Table 3.—*Production Increase*

Field	Production, 1929, Bbl.	Production, 1928, Bbl.	Increase
Barbers Hill	4,486,900	322,950	4,163,950
Sugarland	3,570,800	389,750	3,570,800
Humble	3,043,200	683,100	2,360,100
Refugio	1,992,950	56,600	1,936,350
Raccoon Bend	2,089,900	97,800	1,992,100
Pierce Junction	5,096,400	3,980,400	1,116,000
Clay Creek	841,100	5,600	835,500
South Dayton	2,208,050	1,437,650	770,400
Big Creek	1,443,900	834,250	609,650

These fields alone account for an increase of 17,354,850 bbl. of crude oil.

Barbers Hill.—This is one of the oldest shallow type salt domes that has been prospected for the past decade. It has produced some oil since 1918. It is now producing from sands below 5000 ft. One of the best wells is producing a 34° gravity oil from 6395 to 6418 ft. While

deep sand production was first discovered in October, 1928, development around the edge of the dome has been actively carried on during 1929, until it is obvious that production will encircle the entire dome. The production is coming mostly from sands and sandy shales of Oligocene age and older.

Humble District.—The Humble oil field has produced about 100,000,000 bbl, from the cap rock, sands above the cap rock and from shallow lateral sands. In January, 1929, the South Texas Petroleum Co.'s Morris No. 1 came in flowing 6000 bbl. of 44° gravity oil from a total depth of 5342 ft., over 600 ft. of screen having been set in this well, the formation being sand, shale and sand shale of Jackson, Yegua, Claiborne and Cook Mountain age. Other developments in this same horizon have boosted the production to 16,000 bbl. daily until it is apparent that 1930 will witness enormous production in these new sands.

Port Neches.—The Port Neches salt dome, in Orange County, is one of the important discoveries of the year, inasmuch as the field is located rather favorably in an area that has produced much oil. Up to Jan. 1, the discovery well Kuhn No. 1 had produced over 100,000 bbl. and was still flowing 400 bbl. daily.

Lost Lake.—Another of the newer salt domes in the Gulf Coast that has every promise of developing into a first-class producer is the Lost Lake salt dome, in Chambers County.

Hankamer.—This area, like Mykawa and Genoa districts, is somewhat different from the usual geophysical prospect, the seismograph being possibly unable to detect salt dome characteristics and the torsion balance giving only fairly positive results. The little production that has been developed here is coming from sands of Miocene age.

Refugio.—Development of commercial oil in Refugio field opens up considerable prospective new oil territory. This field was opened to crude oil production in July, 1928, until there are now 75 producing wells with a daily average production of 25,500 bbl. Because of considerable areal extent and unlimited deeper possibilities this field promises to be an enormous producer.

The character of this structure is difficult to work out as the wells do not penetrate any definite recognizable strata, the formations for the most part being unconsolidated sands, gumbo, sandy shales and shales. It is possible the deeper wells encounter uppermost Gueydan of equivalent Oligocene age. However, this is not known and 90 per cent. of the wells never get out of Frio, a very indeterminable formation.

The area of uplift is surprisingly large; the amount of uplift on the upper formations is very little. It does not resemble salt dome structure and most certainly is not a salt dome. Because of the fee ownership here it is difficult to make geophysical surveys, which are desirable in dealing with structures of this nature.

In the Sugarland and Raccoon Bend fields repressuring with waste gas and mixture of air is being practiced with favorable results.

DISCUSSION

D. C. Barton,* Houston, Texas.—The momentousness of the year 1929 has not been quite expressed. The past year or 18 months seems to me either the second, or definitely the third, most momentous year in the history of the Gulf Coast. The most momentous year was 1901 with the discovery of Spindletop; the second probably was 1924, the beginning of the geophysical era.

The first reason for my belief is that the productive area of the Gulf Coast has been extended east, south, southwest, west and north.

In Louisiana we previously regarded the area of commercial production as stopping at Jennings. Farther east, there were shows of oil and small production, but we have now, I think, established that probably there will be commercial production along the coast clear to the Mississippi River, an extension of 100 or 150 miles.

On the southwest the area of good production stopped with West Columbia, but now it extends to Refugio, which is probably a non-salt-dome oil field, but which is in the same position with reference to the coast as the salt-dome oil fields, and which is definitely established as an oil field of high second-class rank. Refugio suggests the extension of the coastal area of good production southwestward from the salt-dome area of southeast Texas, possibly all the way to the Rio Grande. That type of production is going to be hard to define, but Refugio gives us a thought that many similar fields may be there waiting to be discovered.

To the north, Raccoon Bend during 1927 had previously extended production inward, but Clay Creek has carried production yet farther back into the interior of the coastal area.

My second reason is that stratigraphically there has been a downward extension of production. Previous to the past 18 months, most of our production and all of the prolific production came from the Miocene and Oligocene; good, minor production had been obtained from the Jackson, but no prolific production, and only a few small producers had been completed in the Cook Mountain or lower formations. The deep production at Humble, with wells with an initial production of 5000 and 6000 bbl. per day, shows the possibilities of prolific production from the Jackson. The possibilities of Jackson production are emphasized further by Raccoon Bend, at which the production is mainly Jackson. On most of our coastal domes Jackson has not been reached or has only barely been reached. Clay Creek shows the possibilities of Cook Mountain production. There have been many shows from the Cook Mountain, both on the salt domes and on the interior, but no very good production.

My third reason is that during the year the possibilities of deep production, without regard to stratigraphic horizon, have been established. Previous to this year, our deepest production was at 5800 ft. Now at Jennings the practical limit has been pushed down by two wells of the Yount Lee Oil Co. definitely to 7300 ± feet.

My fourth reason is that we have also shown, during the past year, the possibilities of production from deep salt domes such as Esperson. The geologist perhaps calls them non-salt-dome oil fields, but to the geophysicist, who has the torsion balance picture of them, they are definitely deep salt domes. Exploration has not gone far enough on such "geophysical" deep domes to see what the possibilities are, but Orange, one of the old first-class oil fields, is of that type, and theoretically there seems to be no reason why there should not be enormous possibilities from them

* Consulting Geologist and Physicist.

where the normally productive sands are uplifted enough to make favorable reservoirs, but have not been fractured. The geophysicists are showing us an enormous number of those possible deep domes over the Gulf Coast. I have not counted them up, but there are possibilities of a host which we have not discovered yet. It is going to be difficult to find the production on some of them, because they are geophysical domes, mostly torsion balance domes, and it is difficult to place exactly the crest of the dome.

The old estimates of the reserves of the Gulf Coast are slightly over 2100 to 2300 million barrels. At the present time I am multiplying that by $2x$, where x is some number greater than one.

My present tentative estimates are: minimum, 3500; probable 5000; maximum, 9000 million barrels of recoverable reserves in the area between the outcrop of the Oligocene and the Gulf, and between the Rio Grande and the east edge of the Mississippi delta.

Petroleum Developments in Arkansas in 1929

By H. W. Bell,* El Dorado, Arkansas

(New York Meeting, February, 1930)

There was considerable prospecting for new supplies of oil in Arkansas during the past year, regardless of the overproduction affecting the industry throughout the country. Justification for this new work was not lacking, as the local markets more than threatened to absorb a declining production. There were, however, no important new discoveries in the state during 1929.

The McDonald area in sec. 25-15, S.-18 W., threatened to expand into a major producing area. Oil showings had been encountered here in wells drilled by the McDonald Oil Corpn. as early as the fall of 1928. In July, 1929, an initial production of 1000 bbl. of 32° oil was obtained in McDonald Bros. B-3 Wilson, from a sand at 2780 to 2786 ft., which is about 80 ft. higher than the sand previously tested in the neighboring wells. This production declined rapidly. At the end of the year there were six producers making about 200 bbl. per day total. Seven dry holes have temporarily stopped development in that area. The showing of B-3 was sufficient to cause considerable leasing activity. The area lies several miles west of the Louann portion of the Smackover field. The discovery well went to 2873 ft. and found Glen Rose lime in bottom. The age of the producing sand is in doubt; it seems closely related to the Tokio sand.

During 1929, several paying wells were brought in, as a northeastern extension to the Smackover Heavy area, in sec. 34 and 35-15-15, from the Nacatoch sand. Over 20 new wells were drilled and resulted in at least 1500 bbl. production.

The down-dip or off-structure territory contiguous to the Smackover uplift was further tested at various locations with the usual results; that is, a showing of "salt water gas," which soon blew off and in some cases a slight showing of oil. These gas showings, found further down the dip than oil, are the results of the ability of water to take gas into solution at the rate of about 3 per cent. by volume at atmospheric pressure and proportionally larger quantities, if available, at higher pressures (measured on the absolute scale).

During the year no off-structure wrinkles sufficient to trap commercial quantities of oil have been found outside of the other known fields of

* Production Engineer, Lion Oil Refining Co.

El Dorado (South Field), Rainbow (East Field), Lisbon (West Field) and Champagnolle (Shallow).

During December, Joe Modisette brought in a pumper of about 60 bbl. capacity under low pressure in sec. 14-18-14 on Union Saw Mill land. The depth is 2238 ft. and the top of the Nacatoch was probably encountered at 1973 ft. subsea. This location is well surrounded by dry holes checking much lower, except to the northwest. In this direction about ¾ mile in the SE. corner of sec. 10-18-14, C. H. Murphy, Trustee, found the top of the Nacatoch at about 2010 ft. subsea. The suggestion is that this high may connect up with the isolated pool in sec. 5, 6, 7 and 8 of the same township.

To the northwest of the above area, O. W. Estes found encouraging showings in a well in the NW. of the SW. of sec. 35-17-15. The top of the Nacatoch is considered to be 1907 ft. subsea, as oil showings were present at this depth. The El Dorado field, 3 miles to the west, checks from 1901 to 1925 ft. subsea. This well and others strongly indicate that the main producing fields have drawn off the gas for several miles beyond production and left the outlying oil dormant.

Near the close of the year the Marine Oil Co. carried a test below 3500 ft. near Urbana in sec. 10-18-13. At this writing a very promising drill-stem test has been made and casing set. The sand is in a series of red beds and the age is uncertain. This showing has stimulated considerable activity as a large well is expected.

W. M. Coates and associates drilled to 4079 ft. in sec. 32-19-16, encountering considerable Glen Rose (as high as 3404 ft.) lime and anhydrite and securing oil in cores below 4000 ft. Casing was set at 3956 ft. but commercial production was not obtained. The Lion Oil Refining Co. is undertaking the deepening of this well to at least 4500 feet.

Operators of the Smackover field have given serious thought to the feasibility of drilling a community test to 7500 ft., if necessary. Such a test located at the top of the Graves sand high, will possibly be drilled during 1930. The deepest test thus far on structure is the J. E. Crosby 12 Berry near the center of sec. 33-15-15, which went to 4570 ft. and encountered considerable sandbodies, presumably Trinity.

The Louisiana Oil & Refining Co. drilled its 1 Manly, in the East Stephens field to 4502 ft. in Sec. 15-15-19. The top of the Glen Rose is thought by some to have been encountered at least as high as 3100 ft. The well penetrated over 1000 ft. of red beds and it seems likely that the bottom was in Lower Trinity sands. No commercial production was found below the regular Blossom producing sand.

The gas productive area of the Arkansas Valley region was added to by Arkansas Natural Gas Co., McFadden 1, sec. 15-9-21 Pope County. The depth is 1041 ft., rating 43,000,000 ft. and 431 lb. rock pressure.

In this general area, both north and south of the Arkansas River and covering many counties there are numerous structures mapped by government and state geologists. Many thousands of acres have been leased, mostly in large blocks. In this region of high carbon ratios, the chances for gas seem better than for oil.

Decline curves drawn for the several fields indicate average yearly productions shown in Table 1. The perforating of casings in the deeper wells in Smackover, especially, where the Nacatoch, Meakin, Graves, Blossom and Woodbine (?) sands produce, will no doubt boost the production from that field.

TABLE 1.—*Estimated Average Daily Production, Arkansas,* 1930 *to* 1934

Field	1930, Bbl.	1931, Bbl.	1932, Bbl.	1933, Bbl.	1934, Bbl.
Smackover Heavy	39,100	33,750	29,760	26,700	24,200
Light (Louann)	5,380	4,830	4,400	4,070	3,790
El Dorado (South)	3,179	2,909	2,695	2,511	2,357
Rainbow (East)	3,154	1,929	1,300	935	706
Lisbon (West)	875	664	525	429	359
Champagnolle (Shallow)	770	677	606	550	506
Total	52,458	44,759	39,286	35,195	31,918

Petroleum Developments in California during 1929

By Desaix B. Myers,* Los Angeles, Calif.

(New York Meeting, February, 1930)

The consistent upward trend in crude oil production prevailing in California throughout the greater part of 1929, was effectively checked in November by a curtailment program instituted by mutual agreement between operators in four of the major fields. This program artificially reduced daily production to approximately the same daily figure as prevailed in December, 1928.

The large amount of deep drilling during the later part of 1928 and during 1929 has established a potential, however, which is far in excess of refinery needs in the state. Low prices for crude oil which prevailed in California during 1928 continued during 1929. General curtailment continued in the older fields in San Joaquin Valley.

The number of wildcat and exploratory wells drilled throughout California was materially increased, but no major field was discovered unless the recent bringing in of the Ohio Oil Co.'s Recreation Gun Club No. 1 well, near Venice in Los Angeles Basin, during the closing days of 1929 results in such a field.

Significant developments during 1929 were: (1) The discovery of three deeper zones in the Santa Fe Springs field known as the O'Connell, Clarke, and Hathaway; (2) Kettleman Hills development and unanimous agreement to restrict production; (3) developments along the Santa Barbara Coast and the drilling of tideland permits; (4) extensions of some of the older producing areas in the San Joaquin Valley; (5) the Lawndale and Santa Barbara Mesa structures, the former discovered in Los Angeles Basin in 1928, the latter in Santa Barbara County in 1929, proved to be failures; (6) intensive exploration throughout the state and the drilling of a large number of deep wildcat wells; (7) discovery of oil by the Ohio Oil Co. in the Los Angeles Basin at Venice; (8) Long Beach and Ventura Avenue fields maintained steady production throughout the year.

As a natural sequence to the discovery of high-gravity oil fields in Kettleman Hills and at Elwood in 1928, a tremendous amount of exploratory work was done in 1929 in areas underlain by rocks of lower Miocene age, particularly along the Santa Barbara Coast area, the San Joaquin Valley, and the Salinas Valley, where the Vaqueros and Temblor sands were considered to hold possibilities for production.

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* Chief Geologist, Union Oil Co. of California.

As possible structures are eliminated from further consideration by the drilling of wildcat wells, the search for such structures becomes more intensive and the work of the geologist becomes more and more detailed. The California geologist now uses airplane photographs for base maps almost exclusively and depends upon the micropaleontologist for assistance in correlation between widely separated districts and between surface and subsurface strata. In some cases he even resorts to the diving suit for submarine examinations of structural conditions on the ocean bottom adjacent to the shore.

Core drilling as an adjunct to exploration was in common use throughout the year by several companies as preliminary to deeper drilling.

The use of geophysical methods has not resulted, so far as the writer is aware, in the finding of commercial production in California.

During the year 1929 there were many improvements in methods of technology, particularly with respect to the use of heavier equipment for handling extremely deep drilling. Marked improvements were made in the drilling of straight holes and increased efficiency was obtained in gas injection, gas lift, and in general producing methods. The use of subsurface sandstone strata as natural reservoirs for the injection and storing of excess oil was initiated.

Santa Fe Springs Field

Santa Fe Springs, 10 years after its discovery, again dominated the production of the state during 1929, and throughout the year was the center of an almost continuous intensive drilling campaign to deeper sands, the limits of which have by no means been fully determined in this field.

The discovery of the Buckbee zone in July, 1928, was the start of the fields's second intensive drilling campaign, and in January, 1929, the production had reached 100,000 bbl. per day with 229 wells headed for new and deeper sands below the Meyer zone. The exploration which started for the Nordstrom and Buckbee zones was extended and received further impetus when the O'Connell and Clarks zones were discovered early in February. In spite of various attempts at voluntary curtailment a new peak of 295,000 bbl. per day was reached about the middle of July. With this large production and with 63 wells drilling below 6000 ft. the only hope for stabilization of conditions rested with the operation of the California State gas law, which had received the Governor's signature on May 15 and which was to become operative Aug. 31.

Hope of immediate relief was dispelled in September when legal proceedings by the state were postponed until Oct. 14. The production situation became so serious in September, however, that it was not surprising that on Oct. 21 the price of oil in this field was cut approxi-

mately 50 per cent. Curtailment was immediately initiated and by Nov. 5 production at Santa Fe Springs had dropped to 185,000 bbl. per day. A definite curtailment program was agreed upon by the operators of this field, and an umpire was appointed. The close of the year finds the field producing under curtailment 164,400 bbl. per day, which is fully 50 per cent. under the potential production of the field. Two hundred and twenty-one wells are at the present time drilling for the deeper zones.

The deepest well in the world was drilled during 1929—Howard Hathaway, 9350 ft. deep with 4¾ in. set at 8735 feet.

Kettleman Hills

In October, 1928, the completion of the major discovery well on the North Dome, by the Milham Exploration Co., started an active drilling campaign for the deep sands in this area. The Milham, the discovery well, completed in 1928, came in producing 30,000,000 cu. ft. of wet gas per day which, when passed through gas traps, yielded 3600 bbl. of 60° gravity oil.

Of the large number of wells started for the 7000-ft. sands, four wells have made production tests during the year, the largest of these being the Continental Oil Co.'s No. 12-8, which is an offset to the Milham discovery well. This well has produced as high as 175,000,000 cu. ft. of wet gas yielding through gas traps approximately 7000 bbl. of 61° gravity oil.[1] Although approximately 250,000 ft. of hole has been drilled by 40 wells on Kettleman structures during the past year, 14 of which are now below 7000 ft., the estimates of proven acreage in this field can not as yet be made with any degree of certainty.

The steep dips encountered on the west side of the North Dome, together with the unfavorable results of the deep drilling on South Dome, and the general lack of well data from the Middle Dome, have thrown much uncertainty into estimates of productive acreage. It seems likely however, that average cost of development per well in the Kettleman Hills will be far in excess of that in any other field in the United States.

During 1929 a mutual agreement was made between the Department of the Interior and the operators in the area on a development program, which, for the present, restricts production to a minimum and which is to remain in effect during the present overproduction period.

The fact that the deepest test on the South Dome drilled to date has reached 7900 ft. without finding production, indicates that at least a portion of the South Dome may not be in the picture.

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[1] On Jan. 1, 1930, the completion of the Standard Oil No. 8-1-P well at Kettleman Hills for an estimated flow of approximately 4000 bbl., and 101,000,000 cu. ft. of wet gas, brings the number of producers at Kettleman Hills to three.

Santa Barbara Coast

Following the discovery in 1928 of the Elwood field 12 miles west of Santa Barbara, intense activity in wildcat drilling began along the coastal area of California, from Ventura to Guadalupe. Several anticlinal and fault structures underlain by Vaqueros sands in the coastal area of Santa Barbara County have been tested with the result that only one new structure has been added to the commercially productive areas of this district. This single addition, about 8 miles west of Elwood, was proved when the General Petroleum Corpn.'s Erburo No. 1 was completed on Oct. 7 for a daily production of approximately 125 bbl. of 21° gravity oil. In July the Lincoln Drilling Co. completed its Williams No. 1 in the western edge of the old Summerland field for approximately 300 bbl. of 19° gravity oil and a small amount of additional production has been obtained. The most significant development in the Santa Barbara district has been the westward extension of the Elwood field into the ocean by the completion of wells made possible through the erection of costly piers and submarine foundations.

Santa Maria

The year 1929 witnessed an intensive search for oil in the Santa Maria district. Incentive for this drilling was the discovery of oil at Elwood in Vaqueros sands and it was thought that similar conditions might exist in the Santa Maria district.

Salinas Valley

The Salinas Valley was the scene of considerable activity during the year. Most of the evident and known anticlinal structures were leased up and four tests by major companies were started. Two of these tests have been failures while there are two still in progress which are of interest.

Extension of Older San Joaquin Valley Producing Areas

The productive limits of the old West Side field in the San Joaquin Valley have been extended and some heretofore favorably considered wildcat areas have passed into the discard. The limits of the Brown Shale production of Maricopa Flats, south of Thirty-five Anticline, have been extended by various companies, wells being completed for 1000 to 2500 bbl. of 22° gravity oil from the Brown Shale zone.

As a result of a number of tests drilled along the eastern flank of the Temblor Range, in the vicinity of Taft, the western limits of the old producing area have also been extended. The production from this locality has so far proved to be heavy oil of 14° gravity, in spite of the fact that this production comes from the Brown Shale zone.

The East Side fields have seen a gradual drilling program throughout the year with nothing particularly significant discovered.

A total of 145 wildcat wells, in addition to 12 deep tests, the latter being drilled in proven areas exclusive of the Kettleman Hills developments, were drilling in the San Joaquin Valley during the past year.

Two Prospective Oil Fields Fail to Materialize

The discovery of oil at Lawndale, Los Angeles County, in the fall of 1928, and in the Mesa area, Santa Barbara County, May, 1928, resulted during the past year in two intensive town-lot drilling campaigns both of which proved to be failures.

Intensive Exploration throughout State

Wildcat drilling in Los Angeles Basin has almost doubled in the past year as compared with 1928, both in the number of wells drilled and in total footage. This was exclusive of wells drilled inside of semiproven areas after discovery, such as the Inglewood town-lot field.

Small operators drilled more than twice as many wells as the major companies but their total footage amounted to only 2½ per cent. greater, this being due, no doubt, to improved mechanical equipment used by the larger operators enabling them to go to maximum depths in these tests.

With the improvement in core-drilling equipment during the past year, more wells are coring continuously and more care is being taken to prevent drift in holes by frequent surveys. The result is better samples and straighter holes, resulting in more dependable correlations.

There are at present 37 wildcat wells drilling in Los Angeles Basin, 10 of which are being drilled by major operators.

Activities in wildcat drilling in the coastal counties of California for the year 1929 centered around the Santa Barbara district and the close of the year finds the activity at its maximum following the intensive leasing activities earlier in the year. At the close of 1929 there are 51 wells drilling in the coastal counties, compared to 44 drilling wells at the close of 1928.

The prospecting program in the San Joaquin Valley during 1929 embraced a total of 157 wildcat tests of which 12 were wells drilled in the old producing areas in search of new deeper horizons.

Discovery of Oil in Los Angeles Basin at Venice

The area lying between Playa Del Rey and Venice, and bounded on the east by the Inglewood field, has received much attention for a number of years from California operators. A score of wells drilled in this area failed to find production, but the accumulated data and records from these wells were a factor in suggesting the possibility of a "high" along the coast west of the earlier tests. Micropaleontological studies were a distinct aid in correlation.

The Ohio Oil Co.'s Recreation No. 1 well came in to production on Dec. 19, having been drilled to a depth of 6199 ft. On Dec. 31, the production of this well was estimated at 2000 bbl. per day, 24° gravity oil, and 1,200,000 cu. ft. of wet gas.

Long Beach and Ventura Avenue Production Steady

Development for 1929 at Long Beach has been largely along lines defined by 1928 operations. Minor extensions in active areas occurred to the southeast and late in the year a good 1200-bbl. well from the 4500-ft. zone stimulated interest in the Los Cerrites district lying to the northwest. One well was drilled to 9280 ft. but failed to add to the productive penetration of the field.

The limits of the Ventura Avenue field remain practically the same as in 1928, although the southeastern flank might be considered to be slightly extended. Wells are not being completed deeper than in the past year and the field production has been held very steady.

Other Los Angeles Basin Fields

The status of Inglewood, Dominguez, Seal Beach, Huntington Beach, West Coyote and Rosecrans fields remains the same as at the close of 1928.

Production, Stocks and Prices

1. *Crude Production.*—The Santa Fe Springs field dominated California production during 1929. This field produced 76,477,464 bbl. of oil and was 26.18 per cent. of the state's total production. The field's total was 60,383,533 bbl. greater than for 1928, and was but 3,303,811 bbl. less than the field's peak production during 1923.

The total production of the state was 292,036,911 bbl. and is 25.88 per cent. above the production in 1928. This increase in production would have been materially higher had it not been for the effective curtailment program inaugurated during the latter part of the year. (Fig. 1.)

2. *Stocks.*—At the close of 1929 total stocks of heavy crude, heavier than 20° A. P. I., including all grades of fuel, were 113,421,316 bbl., which is an increase of 13,171,423 bbl. over 1928 (Fig. 2). Stocks of refinable crude 20° A. P. I. and lighter increased 23,515,024 bbl.; gasoline stocks increased 5,666,432 bbl., naphtha distillates 1,785,621 bbl., while all other stocks decreased 137,178 barrels.

The total increase of all stocks for 1929 was 44,001,222 bbl. and the amount in storage at the end of the year was 184,002,116 barrels.

3. *Crude Oil Prices.*—On Oct. 21, 1929, prices for Southern California crude above 27° A. P. I., coming from the flush fields, were reduced to 60 c. per bbl. On Nov. 6 to 8, 1929, the former prices ranging from $1.07 to $1.65 in these fields were reestablished. Crude oil prices for other

fields in the state were substantially unchanged throughout the year, with the exception of a decrease of 24 c. per bbl. in Elwood field in March. (Fig. 3.)

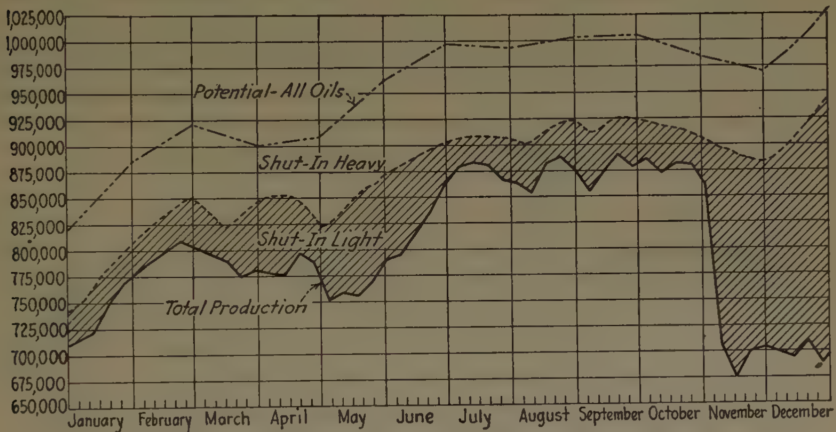

FIG. 1.—CALIFORNIA PETROLEUM PRODUCTION, 1929.

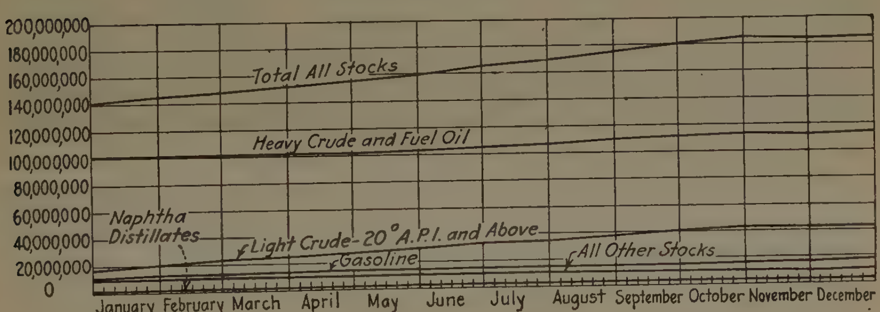

FIG. 2.—CALIFORNIA STOCKS OF LIGHT AND HEAVY CRUDE PETROLEUM, GASOLINE, NAPHTHA DISTILLATES AND ALL OTHER STOCKS DURING 1929.

The retail gasoline price at San Francisco during 1929 ranged from 14 c. to 21 c., tax exclusive, the average being 18 c. Prices for the last five months of the year were 20 c. per gallon.

The price of fuel oil remained unchanged throughout the year at 89 c. per barrel.

PRODUCTION OUTLOOK FOR 1930

An estimate of the production of California for 1930 is unusually difficult at this time due to a number of possible productive areas now undergoing exploration, new deep zones which have been explored but not developed, and to the substantial amount of potential production shut-in under the curtailment program recently inaugurated. For this reason

no definite estimate of future production will be attempted, but the outlook at the close of 1929 is for continued heavy production in California.

In looking ahead to the future, I believe that the possibilities of finding new fields in the state have by no means been exhausted, and that additional large potential production will also be developed from deeper zones in a number of the present producing fields. In addition to this there will be the production of the excess oil now being held in check by curtailment, and there will be an added source from partly depleted fields through increased efficiency in methods of production.

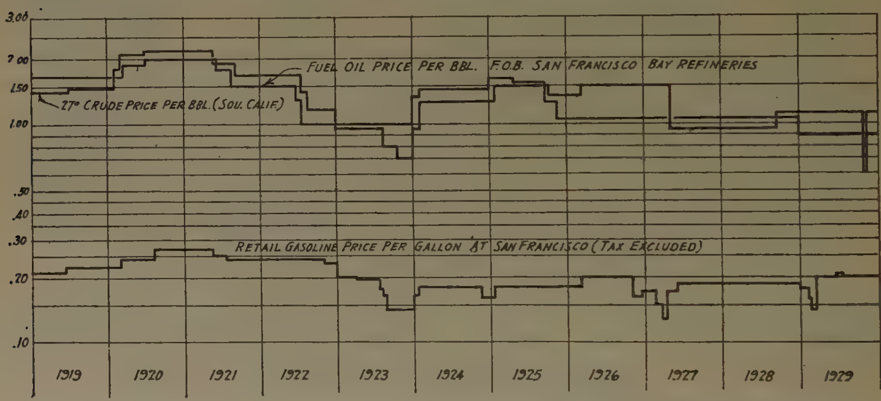

FIG. 3.—PRICES OF CALIFORNIA FUEL OIL, CRUDE PETROLEUM AND GASOLINE, 1918–1929.

The amount of oil actually produced in 1930 will, however, depend upon the effectiveness with which the present curtailment and shut-in programs are applied.

ACKNOWLEDGMENTS

The production charts and graphs accompanying this report were prepared by R. G. Greene, geologist, Union Oil Co. of California. Acknowledgment is also made to L. P. Stockman, statistician, Independent Oil Producers Agency, for statistical information contained in this report.

Petroleum Production and Development in the Rocky Mountain District in 1929

By F. F. Hintze,* Salt Lake City, Utah

(New York Meeting, February, 1930)

Petroleum production in the Rocky Mountain district during 1929 registered a small decline from that of the previous year, conforming with a gradual decrease in the amount of oil produced during the last few years. A number of causes may be mentioned to account for this result, chiefly overproduction in other regions and the apparent desire of operators in this territory to conform to the policy of proration and retrenchment adopted by special agreement among operators in many of the fields. Unit operation has been adopted to control oil production from the Sundance sands in the Salt Creek field, Wyoming, in line with the general effort to stabilize this phase of the industry and prevent excessive drilling of new wells.

Another factor which greatly retarded development in the Rocky Mountain region was the executive order of President Hoover issued in March refusing the award of new prospecting permits to future applicants and threatening cancellation of all existing permits upon which actual drilling had not been done as specified by law.

Only four states in the Rocky Mountain region are important oil producers. In 1929 Wyoming led with an average daily output of 52,600 bbl., followed by Montana, with 10,730 bbl.; Colorado, with 6500 bbl., and New Mexico with 2700 bbl. daily average. These states bear the following percentage relation to total production in the Rocky Mountain district: Wyoming, 72; Montana, 15; Colorado, 9; New Mexico, 4., (Table 1.)

The total average daily production was approximately 73,000 bbl. and the total production of all four states during the year was 26,534,606 bbl. This is 2.7 per cent. of the total oil production of the United States during this period.

Colorado

Although Colorado is not a large producer of oil and natural gas, its oil operations are widely distributed over the state. The Florence field is one of the oldest oil fields in the country, and there are good reasons for believing that the state will retain its place for many years to

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TABLE 1.—*Petroleum Production in Rocky Mountain Region by Fields, 1928–1929**

Field	1928, Bbl.	1929, Bbl.
Colorado		
Craig (Moffat)	422,530	440,265
Ft. Collins	1,032,040	848,925
Boulder	9,310	7,595
Florence	541,510	350,035
Rangely	23,800	35,000
Two Creek	189,960	170,835
Iles	596,040	521,080
Walden	4,870	
Total	2,750,060	2,373,735
Montana†		
Cat Creek	688,689	501,200
Kevin-Sunburst	3,082,198	2,394,910
Lake Basin	3,886	21,490
Pondera	122,659	993,790
Total	3,879,432	3,911,390
New Mexico		
Artesia	399,307	331,660
Bloomfield	5,655	
Caprock	69,231	123,690
Hogback	165,718	117,160
Hospah	1,451	3,290‡
Rattlesnake	214,959	366,625
Table Mesa	50,884	25,830
Total	911,205	968,255
Wyoming		
Alkali Butte	8,134	
Anthills	7,378	
Big Muddy	977,270	825,300
Byron	12,525	5,040
Dallas-Derby	86,518	
Dutton Creek	13,852	12,950
Elk Basin	374,685	282,240
Ferris	19,202	10,500
Frannie	23,720	12,950
Grass Creek	858,758	805,630
Greybull	4,126	2,590
Hamilton Dome	292,646	336,910
Hudson	108,206	175,070
LaBarge	456,408	774,270
Lance Creek	200,872	82,180
Lost Soldier	1,429,297	1,295,840
Mule Creek	122,376	131,530
Oregon Basin	863,163	1,434,832
Osage	149,846	218,400
Pilot Butte	15,988	
Rex Lake	17,676	39,410
Rock River	921,622	849,940
Salt Creek	14,041,079	11,559,520
Simpson Ridge	24,223	21,840
Poison Spider	350,393	331,149
Teapot Dome	6,544	7,350
Torchlight	2,288	3,500§
Total	21,361,795	19,281,041
Total, Rocky Mountain Region	28,920,492	26,534,606

* See Petroleum Development and Technology in 1927, A. I. M. E., 662, for 1926 and 1927 statistics.
† The Montana petroleum situation is reviewed in another paper. See p. 539.
‡ Jal.
§ Notches.

come. The past year has been a satisfactory one notwithstanding a decrease of 14 per cent. in the year's production.

Seven fields have been active producers during the year. The average daily production by fields for the first and last weekly periods of 1929 was as follows:

Fields	Jan. 5, Bbl.	Dec. 28, Bbl.
Moffat (Craig)	1,020	1,140
Ft. Collins	2,290	1,800
Boulder	20	25
Florence	980	655
Rangely	100	100
Tow Creek	630	555
Iles Dome	1,720	1,070
Totals	6,760	5,345

Three producing areas were added during the year. The Berthoud dome, 3 miles west of Berthoud, in Larimer County, on which drilling has been in process for the past several years, became a producer by the completion of a commercial light oil well. The structure is not a large one and the extent of the productive area has not yet been ascertained.

A new gas field was discovered in northern Moffat County, in the northwestern corner of the state, not far to the west of the Hiawatha gas field. The discovery well, Berlin No. 1, was drilled by the Texas Production Co. and proves up a new structure known as Bertram dome, a new high on Hiawatha dome. There are now four producing gas wells in this area ranging from 25,000,000 to 100,000,000 cu. ft. per day in capacity. This gas is being utilized in the Wyoming-Utah gas pipe line to supply Salt Lake City and other Utah towns.

An outstanding development during the year was the discovery of helium-bearing gas in Las Animas County, in southeastern Colorado. The discovery well is located just south of the little town of Thatcher, on the main line of the Santa Fe railroad between LaJunta and Trinidad, about 70 miles southeast of Pueblo. An open flow of 3,000,000 cu. ft. per day was the estimated volume of the gas flow, and the helium content is said to be 210,000 cu. ft. per day, or approximately 7 per cent. This is very unusual in richness and is said to be the richest helium discovery ever made. The gas comes from a depth of about 900 feet.

A wildcat test of great interest and promise is now being drilled by the White Eagle Oil & Refining Co. on Piceance Creek, Rio Blanco County, in sec. 9, T. 2 S., R. 96 W. This well has reached a depth of 2885 ft., and has penetrated two gas sands. In the last sand a flow of 6,000,000 cu. ft. of gas per day was encountered. The test will be carried deeper.

Drilling in the proved fields of western Colorado for the deeper horizons has proved several new sands below the Dakota. In the Moffat dome, production has been proved in the Morrison and Sundance sands of Lower Cretaceous and Jurassic ages, which extends the probable life and ultimate production of this field. In the Iles field, the productive area of the Sundance sand has been defined at a number of points on the dome by the finding of water in the edge wells.

In North Park, Jackson County, the Continental Oil Co. has been engaged during the last few years in testing the North and South McCallum structures, northeast of Walden. On the north dome, oil was discovered and has been produced on a small scale along with a large volume of gas that is chiefly carbon dioxide. The gas expands when it comes from the well and produces such low temperatures that the oil is frozen and appears as a snow. It is recovered when the temperature rises and the frozen carbon dioxide evaporates. If contemplated tests of the refrigerating properties of the gas are successful, the wells of the Continental are sufficiently large to produce a train load of dry ice per day.

New Mexico

New Mexico's oil production comes from two sections of the state, the San Juan basin in the northwest, and Lea and Eddy counties in the southeastern portion. In the San Juan County fields the oil is found in Cretaceous formations and is of unusually high gravity and gasoline content. The production of southeastern New Mexico is obtained from the Permian and Pennsylvanian formations, similar to the large fields of Pecos and Winkler counties, Texas, which lie immediately to the south and southeast of Lea County. The oil is of varying gravities, and is associated with large natural gas accumulations. It is in this part of the state that prospects seem the brightest for large oil development which may place New Mexico in the front rank among Rocky Mountain oil-producing states.

Lea County has occupied the center of the stage and displayed the greatest activity in development during the year. The Lea field, which is close to the geographic center of Lea County, in the northern part of Township 21 S., Range 33 E., has attracted much attention by the performance of two wells, the Texas Production Co.'s No. 1 Lynch, sec. 34, T. 20 S., R. 34 E., and Cranfills and Reynolds' No. 1-B State, sec. 2, T. 21 S., R. 33 E., which together are producing around 3000 bbl. of oil per day. There are nine wells drilling in this area, mostly around the Cranfills and Reynolds well, and three offsets to be located.

The Jal field in the southeastern corner of Lea County includes the wells drilling in T. 25 and 26 S., R. 36 and 37 W. In this area, the Empire Gas & Fuel Co's. No. 1 Lindley, sec. 14, T. 25, R. 36 is

bottomed in lime at 3380 ft. and is estimated to be good for 500 bbl. of oil and 6,000,000 cu. ft. of gas per day. The Humble Oil & Refining Co's. No. 1 Lindley is rated at 680 bbl. per day. There are a number of oil and gas wells in this area completed and shut in, and several others now drilling.

The Cooper area lies to the north of the Jal field and both are on the northern trend of the Winkler County, Texas area in which there are very large producers. This new area consists of Townships 23 and 24 South, Ranges 36, 37 and 38 East.

Still farther north, in Townships 21 and 22 South, Ranges 36, 37 and 38 East, on the same structural trend, is located the Eunice area. It is in this field that the Continental Oil Co.'s discovery well, No. 1 A. E. Meyers, sec. 17, T. 21, R. 36 is located. In this well at a depth of 4001 ft., oil was encountered in a break in the lime and the well flowed at the rate of 20 to 25 bbl. per hr., and made 70,000,000 ft. of gas per day from horizons above the oil, at several levels between 3240 and 3705 ft. The discovery is regarded as opening a new pool and shows the trend of production northward from the Jal pool. In this general area the Marland, Empire and Gypsy companies have completed several oil and gas wells.

The most northerly producing area is called the Hobbs high, in Townships 18 and 19 S., Ranges 36, 37 and 38 E. The center of production in this area is near the center of T. 19 S., R. 38 E. The Humble Oil & Refining Co.'s No. 1 Bowers, sec. 30-18-38, 3 miles northwest of the discovery well in the Hobbs pool is an important test well in this area. At a depth of 2788 ft. a flow of 10,000,000 cu. ft. of gas per day was encountered. More gas was found at 2810 ft., and a good show of oil was encountered at 3143 ft. At 3368 ft. a production test was made showing 25 bbl. per hr., and a later test gave 438 bbl. in 24 hr. The well was drilled deeper and at 3648 ft. a flow of 50,000,000 cu. ft. of gas was encountered. After mudding off this gas, the well is being drilled deeper to test still deeper horizons.

Wyoming

Production of oil in Wyoming during 1929 showed a decrease of more than 2,000,000 bbl. from the 1928 output. For a number of years the production has been on the decline, and this is not more than a normal rate. The largest decline was in the Salt Creek field, which fell off nearly 2,500,000 bbl., which was more than the total for the state as a whole.

The greatest development was in Oregon Basin where the output was almost double that of the previous year. That field now ranks second in size, having surpassed Lost Soldier which has held second place for many years. The daily production in September was 5291 bbl. and in October it was 4089 bbl. Twenty-three wells were completed during the year.

LaBarge showed a large increase over the previous year. This field has 77 producing wells which made 72,889 bbl. in November. The average monthly production was 64,500 bbl., or 2150 bbl. daily for the year. The oil tests from 22 to 36° Bé., and is found at depths under 1000 ft. The Midwest Refining Co. owns and operates a pipe line from Opal, a point on the main line of the Union Pacific R. R., to the LaBarge field.

Perhaps the most outstanding accomplishment of the year has been the discovery of a deeper oil horizon in Frannie and Oregon Basin. Heretofore the deepest pay in these fields was the Tensleep sand of Pennsylvanian age. Oil in commercial quantities was discovered in the Madison limestone of Mississippian age, in a break 70 ft. below the top of the formation, in a well drilled by the Midwest Refining Co. on the Frannie structure. The Madison lime produced some oil at Soap Creek in Montana, and has been found productive in northern Montana and at Turner Valley, in Alberta, but this is the first important Mississippian development in Wyoming.

An accomplishment of great importance in this state was the building of the gas line from Baxter Basin to Salt Lake City to supply it and other Utah towns with natural gas. The cost of the system when completed will be approximately $20,000,000. The capacity of the main line is 60,000,000 cu. ft. per day. The natural gas is marketed in Salt Lake City at the rate of $2.40 per 1000 cu. ft. for the first minimum amount with $0.50 per 1000 cu. ft. as a lower limit where large amounts are used.

Utah and Idaho

Wells have been drilled in various localities in both states but no fields were discovered during the year.

Summary

Under the general policy of retrenchment in wildcat drilling and proration of production, there were fewer oil operations in the Rocky Mountain District in 1929 than for several years previous and oil production declined approximately 2,500,000 bbl. Production in the Salt Creek field declined just about this amount. Deep drilling at Salt Creek is showing up large oil reserves under that field, and with unit operation of the deeper wells there should be a large recovery and increased life for the field.

Several new fields have been found in the different states and there are many interesting and prospective test wells being drilled on structures lately surveyed, so that the outlook is encouraging for continued production for many years to come on a scale as large as at present prevails. Southeastern New Mexico is at present the area of greatest activity and promise.

Petroleum Development in 1929 in the North Rocky Mountain Region, Including Wyoming,* Montana and Alberta

By Ralph Arnold,† Los Angeles, Calif. and O. I. Deschon,‡ Great Falls, Mont.

(New York Meeting, February, 1930)

Deep drilling was the keynote of the more important developments in the North Rocky Mountain region during 1929, with Montana recording the most important achievement through discovery of three new oil fields.

Alberta produced 1,000,000 bbl. of 74° gravity naphtha, showing a considerable gain over 1928, developed a commercial oil pool in Turner Valley and extended that field 8 miles southward.

Wyoming's discovery field was deepened to a second producing horizon, giving impetus to deeper drilling, and practically every Wyoming oil field will have a deep test either this year or in the near future.

Whereas Montana prospecting has been confined to the shallow plains structures, since the discovery of Kevin-Sunburst field, the coming year will see an active search for new oil and gas pools in sharp-dip structures, following the success of prospecting in the Sweetgrass Hills during 1929. A dozen or more structures have been mapped in North Central Montana, several of these straddling the Alberta border. Four structures tested thus far have all shown commercial oil or gas or both.

Sweetgrass Hills

The first important development in the Hills area was the Rogers-Imperial gasser, which had an initial of 51,000,000 cu. ft. of dry gas per day, with a rock pressure of 1080 lb. This well is located on a sharp nose running north from the hills into Alberta. Several wells drilled by independent operators on the American side, on the west flank of reserve structure, have developed a total open flow capacity of 30,000,000 cubic feet.

The third structure tested in the Hills area is known as Bears Den, where commercial oil was found at the base of the Cretaceous at 2470 ft. The existence of oil in three lower sands has been established by two wells on the top of the structure, these two wells finding gas flows of 10,000,000 and 15,000,000 cu. ft., respectively, in the horizon where

* For details of operations in Wyoming during 1929, see p. 537.

† Consulting Geologist.

‡ Editor, *Montana Oil Journal.*

the discovery oil well, 400 ft. down the flank, found production. Bears Den will probably be the most active of the Hills fields during the coming year. A fourth structure, Flat Coulee, is already proved for oil, but no further drilling was done after the completion of the discovery well.

Tests are starting on three other Hills structures said to be equally promising. The oil in these structures is by far the best quality yet found in northern Montana. It is paraffin-base, sweet oil of 44° gravity. A deep test drilled on Bears Den shows black oil of 18° gravity in the Devonian, found at 3300 feet.

Border Oil Field

West of the Hills, on the north flank of Kevin-Sunburst, is a new international oil field, called the Border oil field and sometimes referred to in Alberta as the Red Coulee field. The discovery well was drilled on the Alberta side of the line, but subsurface data indicate that the major portion of the structure is on the Montana side. The discovery well is producing approximately 60 bbl. per day of 34° gravity crude from a sand in the lower Jurassic, at 2400 ft. Because it was 800 ft. low on the north flank of Kevin-Sunburst, the wildcat was not generally noticed until it struck gas and oil. A scramble for acreage by both Montana and Alberta operators resulted in the highest prices for leases and royalties in the history of north Montana oil development. Five strings of tools are now working and several others moving in.

The producing horizon of the Border field is shown as a "stray" sand in Kevin-Sunburst. It appears in only a few spots in that field, thickening to the north and east, as do all other sands, so that there is 300 ft. of true sand in the Sweetgrass Hills area. The Ellis "stray" sand at the Border is reported to be 40 ft. thick.

Recent Projects

The existence of another pool on the flanks of Kevin-Sunburst is indicated by a well completed north of Cut Bank and fully 1000 ft. down dip, showing considerable 30° gravity oil, coming with 5,000,000 cu. ft. of gas. Drilled by the Drumheller interests of Spokane, this well has attracted much attention, but no further drilling has been done during 1929. It is a 3000-ft. drilling and several more wells are projected for 1930.

The success of prospecting at Sweetgrass Hills and the remarkable record of the Turner Valley field, with 5000-ft. drilling, has turned the attention of operators to the sharp-dip structures along the east face of the Rocky Mountains. A sudden realization of the similarity of these folds to Turner Valley led to a rush of lease men, who have leased up more than 200,000 acres, the leases extending from a point west of great Falls, northward 100 miles to the Canadian border, and Albertans

in turn have leased up practically everything along the face of the mountains from the border to Turner Valley.

With the remarkable Royalite No. 4 well of the Imperial Oil Co. still making 600 bbl. of naphtha daily, with no decline from its initial in 1924, Turner Valley saw the record of the Royalite shattered by the home No. 3 well which had an initial of 1000 bbl. of 74° gravity naphtha per day. At the same time a commercial pool was found on the flanks of the structure, which is producing 1400 ft. down structure. An 8-mile south extension, at the close of the year, gave further impetus to development.

The activity in the mountain area led to the starting of five wells in Montana. One near the border on Milk River anticline, not far from Glacier Park, is being drilled by F. M. Fulton, who achieved important successes in Kevin-Sunburst and in Pondera, It will be a 4000-ft. test. Seventy miles south, on Tejon anticline, United Oil & Refining Co., a Cosden subsidiary, is drilling a 3000-ft. test to the Turner Valley horizon. Twenty miles farther south Earl Oil Corpn. of California is drilling at 600 ft. on a 4500-ft. test. Still farther south a Canadian group headed by Neil McQueen of Calgary is drilling a 3000-ft. test on a sharp-dip fold, Crown Butte, with more than 100,000 acres under lease. Another Canadian group is starting a 3500-ft. well on Choteau structure, near the town of Choteau, where several wildcat wells have had showings of oil.

Total Production in Montana

This is considered deep drilling in Montana, although not comparable with deep drilling in other states. Montana has produced in excess of $55,000,000 worth of oil in the nine years of its commercial oil development, and 90 per cent. of this has been produced from wells less than 1500 ft. deep. Cat Creek, first commercial oil field in Montana, has yielded thus far approximately 11,200,000 bbl. of oil, in nine years, an average of about 18,600 bbl. to the acre, from a 20-ft. sand at 1400 ft. Deep tests in this field has been delayed by excessive overriding royalities. Operators have done little or no drilling for several years and the production declined in 1929 to 503,045 bbl., against a peak of 2,201,917 bbl. in 1922. This 54° gravity crude has commanded a premium of $1 per bbl. above the posted field price during the past year. Montana's production in 1929 totaled 4,963,218 bbl., valued at $7,615,638.

Experimental work in repressuring brought considerable increase in production in one lease, leading engineers to estimate that this method will cause present sands of Cat Creek to produce an additional 5,000,000 bbl. of oil.

Kevin-Sunburst and Pondera

Montana's second shallow field, Kevin-Sunburst, also showed a considerable decline in production, owing to lack of drilling, while princi-

pal operators were busy in Pondera, Bannatyne and other newer fields. At one time during 1929 there were only two or three strings of tools at work, but this was increased to 50 strings during the fall months, as operators sought to curb the decline. Meanwhile the price of oil was again increased to $1.85 per bbl. A bonus of 10 c. or more is paid on 80 per cent. of this production of 30° gravity crude, which totaled 2,129,013 bbl. in 1926.

The decline is attributed largely to development of water in wells of the so-called East pool, a local structure of 1200 acres, which has produced in four years approximately 10,000,000 bbl. of oil.

Deep drilling is in early prospect in Kevin-Sunburst. Growing evidence that the source of the oil in this field is some horizon below the Madison lime caused the drilling of a test to the top of the Ordovician, which corresponds to the Wilcox horizon of the Mid-Continent. A 200-ft. sand at 4500 ft. was found to contain oil and gas but not in commercial quantities. The test is located about 400 ft. down dip from the top of the dome. A test to the Devonian is being drilled by the Texas Pacific Coal & Oil Co. This company made an effort to deepen the Frazer-Rice deep test, which found 50° gravity oil at 3390 ft. but the hole was lost. A report issued in 1929 by the U. S. Geological Survey[1] strengthened the belief that this oil is coming from deeper formations.

Pondera, Montana's first 2000-ft. oil field, located 60 miles south of Kevin-Sunburst, set up a record of a total of 144 producers and but four dry holes during the past year. This field, commercially developed in 1928, produced a little less than 1,000,000 bbl. of oil during 1929. It is 36° gravity crude and commands a price of $1.95 per bbl. The field will have paid out the total cost of development by the end of the present year, with no further drilling. However, important north and west extensions were recorded late last fall.

Other Montana Fields

Lake Basin, near Billings, produced 19,000 bbl. of oil with no completions. Carter Oil Co. announced plans to drill another test on Six-shooter anticline after having completed a 5,000,000-ft. gasser in 1929. Prairie Oil & Gas Co. has taken over Porcupine dome, in Rosebud County, and is drilling two tests on a block of 100,000 acres. Development of Porcupine has been held up by the Government permit situation.

Ohio Oil Co. brought in its first Montana oil field during 1929, getting commercial production on Dry Creek structure, in Carbon County in south central Montana. Ohio is drilling a second well while the discovery well is making about 35 bbl. of gasoline per day with ordi-

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[1] A. J. Collier: The Kevin-Sunburst Oil Field and Other Possibilities of Oil and Gas in the Sweetgrass Arch, Montana. U. S. Geol. Survey *Bull.* 812–B (1929).

nary separators, from a 11,000,000 cu. ft. flow of gas, coming from the Frontier sand at 4458 feet.

Gas Development

Gas development is the outstanding feature of the North Rocky Mountain development for the coming year. Several projects are reported nearing maturity. Minnesota-Northern Power Co. has extended its lines from the Baker-Glendive anticline to supply all eastern Montana towns and cities and is steadily pushing eastward through North Dakota, with the Twin Cities as the ultimate objective. Another project announced by this company is the construction of a 300-mile line along the "high line" of the Great Northern railway from Chester, near the Sweetgrass Hills, to the Dakota border, coupling in low-pressure gas from Bowdoin dome.

This same company built during 1929 a line from Kevin-Sunburst to Valier, Conrad and Choteau, Mont., a 93-mile line which parallels the Hope Engineering Co. line to Great Falls.

That gas will be piped to the mining centers at Butte and Anaconda, providing a 50,000,000-ft. industrial and domestic load, is now considered a certainty. One plan is to extend the Great Falls line to Butte, coupling in Canadian gas, providing an export permit can be secured. A second plan is to build a new line from the Sweetgrass Hills direct to Butte. A third project calls for a 200-mile line from northern Wyoming to Butte.

More pretentious projects have been talked of one for the construction of a line to Spokane and thence to Puget Sound and another for the construction of a line to Minneapolis.

Wyoming gas is now going to Salt Lake, the line from Baxter Basin having been completed during the past year. It is rumored that Montain Fuel Co. may extend this line from Salt Lake City to the Pacific Coast.

Appalachian Petroleum and Natural Gas Fields during 1929

By Charles R. Fettke,* Pittsburgh, Pa.

(New York Meeting, February, 1930)

The outstanding event of the year 1929 in the Appalachian area was the intensive drilling activity in the Bradford and Richburg pools of northwestern Pennsylvania and southwestern New York State, particularly the former, in connection with the continued extension of the five-spot system of water-flooding. More new development work was undertaken and completed than during any previous year since reclamation methods were first applied. This was due in part to an excellent price for oil and in part to discovery of the fact that more intensive methods (five-spotting) yielded greater profit.

While several oil wells of comparatively large initial production were completed, no new oil pools of significance were discovered in the Appalachian area during the year. A number of small gas pools were opened in areas already surrounded by producing wells and at least three others in areas located some distance from any producing pools.

Petroleum Development

According to statistics of the U. S. Bureau of Mines, 33,757,000 bbl. of petroleum were produced in the Appalachian field during 1929 as compared to 31,060,000 bbl. in 1928.[1] Of the total 1929 production, 23,391,618 bbl. consisted of Pennsylvania grade oil as compared to 21,096,710 bbl. in 1928. The 1929 Pennsylvania grade production represents an increase of 37.4 per cent. over that of 1924. This increase can be attributed largely to the rapid development of water-flooding in the Bradford and Richburg pools.

The Bradford field of northwestern Pennsylvania and adjacent portions of New York State experienced the busiest year since the boom days of the early eighties. Wells completed during the year totaled 2679.[2]

In spite of the high prices asked for acreage, which in some of the choicest territory has been as high as $6000 an acre, a considerable number of properties changed ownership during the year. There is at present a pronounced tendency to consolidate the great number of small individually operated properties into larger units.

* Professor of Geology and Mineralogy, Carnegie Institute of Technology.

[1] *Oil & Gas Jnl.* (Feb. 6, 1930) 145.

[2] *Oil & Gas Jnl.* (Jan. 30, 1930) 279.

TABLE 1.—*Total Crude and Pennsylvania Grade Production by States*
Barrels of 42 U. S. Gallons

State	Total Crude		Pennsylvania Grade	
	1929	1928	1929	1928
Kentucky	7,776,000	7,359,000		2,603,000
New York	3,346,000	2,603,000	3,346,000	2,875,710
Central and Eastern Ohio	5,224,000	5,434,000	2,653,618	9,956,500
Pennsylvania	11,805,000	9,956,500	11,805,000	
Tennessee	19,000	46,000		
West Virginia	5,587,000	5,661,500	5,587,000	5,661,500
Appalachian area	33,757,000	31,060,000	23,391,618	21,096,710

In the Allegany field of southwestern New York State, which includes the Richburg and several other smaller pools, 406 wells were completed during the year. This field produced 2,951,992 bbl. of oil in 1929 as compared to 2,093,385 bbl. in 1928.[3]

An area of approximately 350 acres was proved productive in the new Fifth sand pool discovered late in 1928 by the T. W. Phillips Gas & Oil Co. 2 miles southeast of Ekastown in Buffalo Township, Butler County, Pennsylvania. About 16 wells, ranging from 3 to 240 bbl. initial production, were drilled in this pool during 1929. By the end of the year its limits were pretty well defined. The wells have proved rather disappointing in that they decline rapidly.

In January, 1929, the Peoples Natural Gas Co. opened a small pool in the Bayard sand about 2½ miles northeast from Clover Hill in Fallowfield and West Pike Run townships, Washington County, Pennsylvania. The discovery well had an initial production of approximately 200 bbl. In an area of about 380 acres, 12 wells have been completed, varying in initial production from 15 to 200 bbl. Four are now drilling.

Perhaps the outstanding oil well of the year was that of the Manufacturers Light & Heat Co. on the H. A. Day farm in Morris Township, Washington County, Pennsylvania, which on March 25, 1929, started off with an initial production of 490 bbl. from the Fifth sand. At the end of 6 months, it was making 125 bbl. and at the close of the year, when tubed, it was still flowing by heads at the rate of 50 bbl. Another well drilled 800 ft. to the south had an initial production of only 35 bbl. No new pool was opened by this discovery, inasmuch as the tract lies on the eastern edge of an already developed field.

The outstanding development in Kentucky occurred in the Tri-County area of Ohio, Daviess and Hancock counties in the western

[3] *Oil & Gas Jnl.* (Jan. 30, 1930) 281.

part of the state. In this area, 1070 new wells were completed, of which 301 were dry, 48 were gas wells and 721 were oil producers with an initial production totaling 45,839 bbl. This increased production was more than the existing pipe lines were able to handle, necessitating a 30-day shutdown of drilling, extending from Dec. 15, 1929, to Jan. 15, 1930.[4]

According to Walter F. Pond, State Geologist of Tennessee, the production in the Clay County district of that state fell off considerably in 1929 and the total production of the state declined from 46,983 bbl. in 1928 to 22,551 bbl. in 1929.

Natural Gas Development

Probably the outstanding gas pool developed in recent years in the Appalachian area is the Clinton pool, in Franklin and Green townships, Summit County, Ohio, south of Akron and somewhat to the east of the old producing territory of Central Ohio in the Clinton sand. This pool was discovered by S. J. and F. A. Brendel in July, 1927. The first well located in this vicinity by F. A. Brendel encountered production in the Clinton sand. About 90 wells outline a productive area of approximately 15,000 acres yielding about 100,000,000 cu. ft. of gas per day.

Early in 1929, considerable interest was aroused in Ashtabula County, Ohio, by a flow of 1,500,000 cu. ft. of gas, with a rock pressure of 900 lb., in the Clinton sand, in a well 2 miles southwest of Conneaut, at a depth of 2730 ft. Three other wells drilled later in the immediate vicinity encountered open flows of from 200,000 to 6,000,000 cu. ft. in the Austinburg (Oriskany) sand at the base of the Onondaga limestone, considerably above the Clinton horizon.

Late in 1929, a well 1½ miles north of Yorkshire, in Erie County, New York, discovered 1,500,000 cu. ft. from the Red Medina horizon. This discovery may lead to the opening of a new Medina sand pool some distance to the south of the main producing territory in the Medina sand of western New York State. It is fairly well established now that the Clinton gas and oil horizon of central Ohio is the equivalent of the Medina gas horizon of New York State.

Deep drilling in the Richburg area of Allegany County, New York, failed to develop any further gas production during 1929.

There was considerable leasing and geological exploration during 1929 over a large area east of the present gas-producing territory of western New York State. Several deep tests will probably be completed during 1930.

Near Williamsburg, about 2½ miles south of Clarion in Clarion County, Pennsylvania, a new gas pool discovered during the previous

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[4] *Oil & Gas Jnl.* (Jan. 30, 1930) 175.

year has proved productive over an area of about 1500 acres. The gas was encountered in a sand near the base of the Mississippian; 18 wells with open flows ranging from 100,000 to 2,250,000 cu. ft. and two dry holes were completed during 1929.

In the gas territory of northwestern Pennsylvania in McKean, Venango, Forest, Elk, Clarion, Jefferson and Armstrong counties, approximately 400 wells were completed during 1929, with an average open flow of 140,000 cu. ft.; 18 per cent. of this number were failures. Perhaps the largest individual well was drilled near Walston, in Jefferson County, with an open flow of approximately 15,000,000 cubic feet.

About 6 miles southeast of Washington, in Amwell Township, Washington County, in southwestern Pennsylvania, the Greensboro Natural Gas Co. during 1929 opened a small gas pool, about 160 acres in extent, in the Gantz sand. Of 10 wells drilled in the vicinity, four were failures. The two best producers had open flows of 1,400,000 and 5,250,000 cu. ft. per day respectively.

Wildcat drilling in southern West Virginia during 1929 resulted in the discovery of a new gas pool of both local and regional importance in the southwestern part of Monroe and adjacent portions of Summers County, West Virginia, near Bozoo Post Office in the former county. The discovery well encountered an open flow of 239,000 cu. ft. of gas at a depth of 3105 ft. in a sand that David B. Reger, Associate Geologist of the West Virginia Geological Survey, has correlated with the Weir sand in the lower part of the Pocono sandstone series. Another well, 1¼ mile north of the discovery well, drilled by the same company, opened up a flow estimated at 2,500,000 cu. ft. daily at a depth of 2916 ft. in the Squaw sand, which lies about 90 ft. above the Weir. This well developed water trouble shortly after completion and is now being deepened to the Weir sand. While these wells would attract little notice if located in the developed gas fields of West Virginia, they are of unusual interest because they are more than 40 miles from the nearest small gas pool and more than 50 miles from the well known gas areas of southern West Virginia and only 6 miles north of the St. Clair overthrust fault along which there is a displacement of 5000 ft. or more.

Petroleum Developments in Indiana and Illinois in 1929*

By Alfred H. Bell,† Urbana, Ill., and Paul F. Simpson,‡ Indianapolis, Ind.

(New York Meeting, February, 1930)

The year 1929 was one of continued activity in the petroleum industry of Indiana and Illinois but the new production obtained has not been sufficient to offset the decline in the production of the old wells. (Table 1). Drilling costs have not changed materially during the year and the prices of crude oil have increased slightly so that the prospects for further testing are good. The total number of completions in Illinois in 1929 (Table 2) was greater than for any year since 1917. More than half of these were in the Dupo field, St. Clair County, and the development of this field was largely responsible for the increased ratio of producers to dry holes in the state as a whole. In the southeastern Illinois field which has produced about 97 per cent. of the state's petroleum the number of completions was greater than in 1928 and the percentage of producers was a little higher. Although a number of scattered wildcat tests were drilled most of them were not located on favorable structure and the only noteworthy discovery was that of a shale-gas horizon at shallow depth in Morgan County in western Illinois where gas has been produced for a number of years from sandstone and limestone. In Indiana the number of completions (Table 2) was only slightly less than in 1928. Most of the new wells were drilled in the southwestern part of the state, which now produces more than 90 per cent. of Indiana's petroleum.

Table 1.—*Petroleum Production in Indiana and Illinois*, 1925–1929

	Indiana			Illinois, Bbl.
	Southwestern, Bbl.	Northeastern, Bbl.	Total, Bbl.	
1925	649,000	180,000	829,000	7,863,000
1926	658,000	150,000	808,000	7,760,000
1927	726,000	126,000	852,000	6,994,000
1928	963,000	90,000	1,053,000	6,462,000
1929	912,000	65,000	977,000	6,304,000

* By permission of the Chief, Illinois State Geological Survey.

† Geologist, Petroleum Section, Illinois State Geological Survey.

‡ Indiana State Gas Supervisor

TABLE 2.—*Wells Drilled in Indiana and Illinois in* 1929

States	Completions	Gas	Oil	Dry	Uncompleted	Initial Production	
						Oil, Bbl.	Gas, Cu. Ft. per Day
Indiana...........	193	39	70	84	37	2,427	38,865,000
Illinois............	433	18	313	101	13*	16,030	4,588,000

* Wildcats only.

The most interesting development was the drilling of several large gas wells in Gibson County. It is probable that most of the new drilling in 1930 will be in southwestern Indiana and southeastern Illinois which are part of the same petroliferous province. In southwestern Illinois it is expected that a number of deep tests will be made on the known structures in that area.

Petroleum Developments in Mississippi during 1929*

By Ralph E. Grim,† University, Miss.

(New York Meeting, February, 1930)

With the exception of the extreme northeastern part of the state, Mississippi lies wholly within the Gulf Coastal Plains. The largest structural feature definitely proved is the so-called Jackson structure[1] in the central part of the state. This structure is mainly the result of the burial of an igneous ridge on the old sea floor. The ridge trended in a northwest direction from about the town of Jackson in Hinds County into southeastern Arkansas. The present structure is the burial of the ridge.

Recent detailed surface work by major oil companies has suggested smaller structures in other parts of the state, but so far they have not been definitely proved. Also considerable magnetometer and seismographic work has been done in the northern and central part of the state. The results of the operation of the seismograph are not yet available, but the magnetometer located many "magnetic highs" in this part of the state. Outside of the area of the Jackson structure, the exact cause for this magnetic variation is not known. In a portion of south Mississippi, considerable seismographic work has been done recently in an attempt to locate salt domes. While the details are not available, it has apparently met with little success.

Prospecting by districts during the past year may be summarized as follows:

Five wells of importance were drilled in the Amory district of east Mississippi. This district comprises all or parts of Monroe, Lee, Itawamba, Prentiss, Alcorn and Tishomingo counties. Small gas was discovered at about 2500 feet.

Several wells were drilled in the Jackson district which is located in part or all of Hinds, Rankin, Madison and Yazoo counties. Some of these wells were abandoned and one was shut down most of the year.

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* Published with permission of the Director, Mississippi Geological Survey.

This paper has been condensed for inclusion here and a limited number of separates of the complete paper are available. The latter contains considerable detail relating to the petroleum geology of Mississippi.

† Mississippi Geological Survey.

[1] O. B. Hopkins: Structure of the Vicksburg-Jackson Area, Mississippi. U. S. Geol. Survey *Bull.* 641-D (1916).

One well in Warren County is drilling and promises to be interesting if carried deep enough. Depths at which drilling ceased varied from approximately 3300 to 4100 ft. As a result of geophysical work on the Jackson structure in the past year, 1930 will probably show continued drilling activity.

A well drilled in 1928 in the Meridian district surrounding the city of Meridian in Lauderdale County, was authentically reported to have encountered a sand saturated with oil at 2812 ft. in the Tuscaloosa formation. This renewed the activity in this district and enlisted the interest of the major oil companies. There are two wells drilling in this area at the present time. Leasing has been active and very probably additional wells will be drilling in the near future. Two wells are being drilled in the Water Valley district which surrounds the town of Water Valley, situated in Yalobusha County.

Investigations made years ago north of the town of Houston in Chickasaw County, has led to intermittent drilling in this area by local companies. A well which has been drilling during the past year is shut down at present due to litigation. In Lincoln County in south Mississippi, a well is still drilling. The reason for the location of this well is not known.

Chapter XIV. Foreign Production

World Petroleum Production during 1929

By Valentín R. Garfias,* New York, N. Y.

(New York Meeting, February, 1930)

The world's petroleum production in 1929 is estimated at 1,479,335,-000 bbl., which represents an increase of about 157,000,000 over 1928, as compared with an increase of 61,000,000 bbl. in the previous year.

During the present year a more definite policy of conservation has been seriously considered by the foremost executives of the companies controlling the bulk of domestic and foreign production, and the United States Government has taken an active interest in the development of this program. Definite steps have already been taken and the industry is gradually establishing a foundation for closer and more intelligent cooperation. The entire program, however, is still in a formative or experimental stage.

Among other salient constructive steps may be mentioned the establishing of tentative agreements of unification in the price of oil products exported from the United States, the putting into effect of a gas conservation law in California, and the marked tendency towards consolidations of the various branches of the industry into larger units.

The publication of the draft of the proposed petroleum law in Colombia and of the Mexican Labor Law, on the other hand, has created paprehension and uncertainty. It is confidently expected, however, that these perliminary drafts will be materially modified before the laws are promulgated, or otherwise they may destroy the interest they are intended to protect.

United States

Production in the United States, which remained stationary during 1927 and 1928, increased about 105,000,000 bbl., or 11.6 per cent. This increase is due primarily to deeper drilling in the California fields and to the discovery of new pools in Texas and Oklahoma. The progress of the conservation program was marked by the action of the Government in stopping further permits to drill on Government lands; by putting into effect early in September the California Gas Conservation Law, and by

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WORLD PETROLEUM PRODUCTION
Thousands of Barrels

	1929[a]	1928[b]	1927[b]
1. United States	1,006,700	901,474	901,129
2. Venezuela	138,900	106,000	63,134
3. Russia	98,000	87,800	77,018
4. Mexico	44,700	50,150	64,121
5. Persia	43,000	42,080	39,688
6. Dutch East Indies	36,000	28,500	25,967
7. Rumania	33,000	30,600	26,368
8. Colombia	20,400	19,900	15,002
9. Peru	12,500	11,970	10,135
10. Argentina	10,000	9,100	8,630
11. Trinidad	8,700	7,750	5,712
12. India	8,300	8,300	7,878
13. Sarawak	5,300	5,290	4,943
14. Poland	4,700	5,530	5,342
15. Japan	2,000	1,800	1,700
16. Egypt	1,900	1,840	1,267
17. Sakhalin	1,200	509	440
18. Canada	1,100	618	477
19. Ecuador	1,000	1,090	537
20. Germany	700	683	663
21. Irak	500	650	200
22. France	500	520	504
23. Czechoslovakia	170	150	149
24. Italy	43	43	44
25. Others	22	23	25
	1,479,335	1,322,370	1,261,073

[a] Figures for 1929 are in part from *World Petroleum.*
[b] U. S. Bureau of Mines.

the Kettleman Hills, Oklahoma City and West Texas conservation agreements. Crude stocks increased about 37,000,000 bbl. during 1929 compared with an increase of 17,000,000 the previous year. The average shut-in production is variously estimated to be from 30 to 60 per cent. of the total.

VENEZUELA

The 1929 production of the Venezuelan fields was 138,900,000 bbl. showing an increase of about 33,000,000, or 30 per cent. over 1928; the output has been to some extent regulated by mutual conservation agreements between the leading producers. Other important developments were the completion of a refinery in the island of Aruba, and the laying of a pipe line from the Colon District, which will bring into the Maracaibo market early in 1930 the higher grade oil from the Tarra field.

Russia

Production in Russia has kept its steady increase and is estimated at 98,000,000 bbl., representing 7 per cent. of the world output, a percentage which the country has maintained for the last 3 years.

Mexico

Contrary to the general upward trend in every important producing country, Mexico again registered a decline in output. This steady decline started in 1921 and has continued to date. The 1929 production was 44,700,000 bbl., or 5,000,000 bbl. less than 1928. The country may have produced this year less than Persia, and, should the downward course continue, possible Dutch East Indies will outrank Mexico during 1930. The outstanding event, besides the speedy suppression of the revolution which started in March, has been the publication of the draft of a new labor law. Some of the provisions of this law have caused widespread apprehension in some quarters. A new administration has been established in Mexico, and as it should be in power for its full term, its policy in regard to the petroleum industry should be a controlling factor during the next 6 years.

Persia

With a production variously estimated between 43,000,000 and 46,000,000 bbl. during 1929, Persia may have displaced Mexico as fourth in rank. Areas to the north and south of Mesdjid-i-Suleiman, the main producing field, have been proved, and although no production is obtained from these areas, it is reported that the shut-in production from these and other regions is in excess of the present yield.

Dutch East Indies

The production of Dutch East Indies increased somewhat, the preliminary figures of 35,000,000 bbl. indicating that it has surpassed the Rumanian output.

Rumania

Production in Rumania has increased steadily during the last 10 years and reached the figure of about 33,000,000 bbl. in 1929. A more liberal petroleum law has been promulgated, bringing about a wider foreign interest in the Rumanian fields than heretofore.

Colombia

Production in Colombia has been maintained to the capacity of the existing pipe lines, about 20,000,000 bbl., with no marked change from 1928. The outline of the new petroleum law has caused widespread

disappointment, since it is realized that if the law becomes effective in its present form it will serve to postpone indefinitely major operations by bonafide operators.

Peru

The production of Peru shows a small increase and totals about 12,500,000 bbl., or 500,000 over the preceding year.

Minor Producers

Of the countries listed as minor producers, Sakhalin, Canada and Germany showed important developments.

Petroleum Development in Venezuela during 1929

By E. L. Estabrook* and J. A. Holmes,† New York, N. Y.

(New York Meeting, February, 1930)

Venezuela has continued during 1929 to demonstrate that it is destined for many years to come to be one of our most important sources of crude petroleum. The producing fields of the Bolivar Coastal district along the east side of Lake Maracaibo have continued their phenomenal production, and two new fields have reached the near producing stage, while the results of deep test wells have strengthened the predictions and expectations that oil will be found and produced from many other pools and from several different geological formations. The finding of these new oil pools is not going to be easy, because the surface evidences of geological structure are scanty, and the subsurface problems are difficult, but intelligent effort backed by ample resources may be counted upon to overcome these obstacles and lead to a continued increase in the number of producing fields in Venezuela.

During 1929 the total production of Venezuela was approximately 135,953,000 bbl., an increase of nearly 30,000,000 bbl., or 28 per cent., as compared with the preceding year. During 1929 oil in steel storage in Venezuela decreased from 13,000,000 to about 11,000,000 barrels.

Tables 1, 2 and 3 briefly summarize Venezuelan production by fields and by years, and show the trend of production since its establishment on a commercial basis.

Table 1.—*Production of Crude Oil in Venezuela by Years,* 1917 *to* 1929

All Figures in Barrels of 42 Gallons

Year	Total Production Venezuela, Bbl.	Year	Total Production Venezuela, Bbl.
1917	227,000	1927	63,181,000
1918	368,000	1928	106,000,000
1919	258,000	1929	135,953,000*
1920	548,000	Grand Total Since Inception	380,791,000
1921	1,544,000	Increase, 1929 over 1928	29,953,000
1922	2,448,000	Per cent. Increase	28.2
1923	4,170,000	Per cent. 1929 Production of Total	35.7
1924	9,234,000		
1925	20,219,000		
1926	36,641,000		

* Includes estimate for closing period of 1929.

* Consulting Petroleum Engineer, Pan American Petroleum & Transport Co.
† Petroleum Engineer, Pan American Petroleum & Transport Co.

General Field Developments

The Bolivar Coastal fields on Lake Maracaibo continue to be the center of interest in Venezuela and the source of the greater part of production. The scene of greatest drilling activity shifted during the year from Lagunillas to Ambrosio where the Venezuelan Oil Concessions, Ltd., and the Venezuela Gulf Oil Co. indulged in a spirited line fight along the lake shore. A sharp southward plunging syncline was found

Table 2.—*Production of Crude Oil in Venezuela by Fields,* 1928–1929

Region	1928	1929†
State of Zulia, Bolivar Coast:		
Ambrosio	2,103,812	8,000,000
La Rosa	25,122,655	31,400,000
Punta Benitez, Unity and Tia Juana	1,227,898	620,000
Lagunillas	61,554,219	78,980,000
Total Bolivar Coast	90,008,584	119,000,000
Mene Grande and Misoa	13,287,716	14,100,000
Mara*	10,231	10,000
La Paz*	15,408	29,000
Totumo*	52,032	51,000
La Tarra and Rio de Oro*	134,304	282,000
Total Other	13,499,691	14,472,000
Total Zulia	103,508,275	133,472,000
State of Falcon:		
El Mene	1,866,538	1,985,000
Hombre Pintado	29,857	40,000
Dabajuro*	6,955	18,000
Urumaco*	28,087	85,000
Total Falcon	1,931,437	2,128,000
Eastern and Central Venezuela:		
Maturin, (Quiriquire)*	32,163	
Guanoco	530,525	353,000
Total East and Central	562,688	353,000
Grand Total Venezuela	106,002,400	135,953,000

* Indicates fields producing for fuel only.

† Includes estimate of production for closing period of 1929.

between the La Rosa and Ambrosio fields, but the oil sands continued to be productive entirely across it, and the two fields are now completely connected. The productive area at Ambrosio is limited on the west by an unconformity which cuts out the oil sands, but the field is still open for some slight extension north and south. Eastward, on land, the Venezuelan Oil Concessions, Ltd., has a large block of productive acreage which is being gradually drilled up.

At Lagunillas, the year has been fairly quiet, with development drilling confined to the territory surrounding the Miraflores, Gatun, Titicaca, Lago and Laguna parcels. Several exploratory wells have been drilled in various directions in the lake, of which the Venezuela

TABLE 3.—*Number of Wells, Average Depth, Gravity of Crude, and Estimated Potential Production*

Approximate figures as of Dec. 31, 1929

Region	Productive Wells, Number†	Average Depth, Ft.	Gravity of Crude, Deg. A.P.I.	Estimated Daily Potential, Bbl.
State of Zulia, Bolivar Coast:				
Ambrosio	94	2,421	21.5	14,600
La Rosa	615	2,470	15.0 to 27.5	91,500
Punta Benitez and Unity	42	2,463	18.7 to 27.4	9,050
Tia Juana	7	2,611	16.0 to 18.0	6,850
Lagunillas	477	3,499	13.4 to 19.0	316,900
Total Bolivar	1,235			438,900
Los Barrosos*	2	2,429	16.0 to 22.0	
Mene Grande	178	2,122	16.6 to 27.6	53,750
Mara*	1	3,840	30.9	15
La Paz*	22	1,397	22.0 to 28.0	4,000
Concepcion	59	1,579	34.4	4,500
Totumo (Rio Palmar)*	8	2,153	19.7	2,500
La Tarra and Rio de Oro*	25	1,935	23.0 to 39.3	24,800
Total Other	295			89,565
Total Zulia	1,530			528,465
State of Falcon:				
El Mene	166	1,325	33.0 to 43.5	5,000
Hombre Pintado	4	2,021	19.0 to 29.0	350
Dabajuro*	1	4,500	19.0 to 30.0	500
Urumaco (El Mamon)*	2	3,419	34.5	1,500
El Mene del Salto	10	956	44.0	1,300
Las Palmas	4	1,804	32.0 to 42.0	
Total Falcon	187			8,650
Eastern and Central Venezuela:				
Maturin (Quiriquire)	11	2,505	19.0	4,000
Guanoco	10	1,142	10.5	1,200
Total East and Central Venezuela	21			5,200
Grand Total Venezuela	1,738			542,315

* Indicates fields producing for fuel only.

† Includes wells closed in, working over, and inactive.

Gulf Oil Co.'s Lagon No. 1 (Table 4), located more than 2 km. south of the field, is the most important. This well was completed in December for a production of 680 bbl. of oil, 16.2° A. P. I. gravity, at a total depth of 4984 ft. This well is nearly 600 ft. structurally lower than any other

well in Lagunillas and increases the vertical range of production between the north and south ends of the field to about 2700 ft. Lakeward the Lago completed well No. 479 somewhat over 3 km. from shore, which showed for a good well but was not tested. Farther north, 2 km. offshore from Punta Tamares, the Lago completed well No. 890, producing about 150 bbl. of 22° A. P. I. gravity oil at a total depth of 3628 ft. The character of the oil confirms the geologic explanation that the Lagunillas sands have pinched out, and that the production is being obtained from the Santa Barbara group and possibly from the upper part of the underlying El Mene shale (Miocene). The Santa Barbara is the lowest producing formation in the La Rosa field and has previously been identified as far south as Lagunillas village.

The areal limits of the Bolivar Coastal fields are as yet unknown except at a few points where the oil sands are cut out by the basal unconformity, but an area 50 km. long and from 2 to 6 km. wide has already been blocked out as proven or semiproven acreage. The immensity of the area makes it certain that a large production will be maintained for many years to come.

No developments of particular importance can be recorded in the other producing fields of the Maracaibo Basin. Substantial amounts of oil were produced at Mene Grande and El Mene, but the suspension of activities continued at Concepcion and La Paz. In the District of Colon, the development of the La Tarra field has been actively carried on and a pipe line is being laid to a ship-loading point at the mouth of the Escalante River. Early in 1930 shipments are expected to begin at the rate of 20,000 bbl. per day. The Totumo field has not yet reached the producing stage, since the 10 wells so far completed in this area have been too small to be considered commercial producers in such an isolated field.

New Pool in State of Falcon

In the State of Falcon, the new fields discovered in 1928 continue to be developed, and one new discovery was made. In May, 1929, the British Controlled Oilfields, Ltd., brought in their Media No. 2 with a production of 200 bbl. per day of 38° A. P. I. oil. The new pool lies within the faulted zone that extends through El Mene to Dabajuro and is, therefore, expected to be of rather limited area. The development work at Dabajuro and Urumaco has added considerably to the proved area in both fields. The Hombre Pintado field has been connected by pipe line with El Mene, and oil is being shipped via Alta Gracia. Nothing spectacular has yet been discovered in the State of Falcon, but it appears probable that a number of small pools will be found which will produce substantial amounts of high-grade oil. The geographic align-

ment of the pools along the mountain front will facilitate the collection of the oil by a single trunk pipe line.

The El Mene del Salto field in eastern Falcon is expected to enter into commercial production during 1930. A 6-in. pipe line is being planned which will extend to tide water at the port of Chichiriviche.

TABLE 4.—*Wildcat Wells in Venezuela*, 1929

District	Well No.	Company	Date Spudded	Status at End of 1929
Falcon:				
Acosta	Aguide 1	North Venezuela Petroleum Co.	March, 1929	Drilling below 2700 ft.
Buchivacoa	Cardon Solo 1	British Controlled Oilfields, Ltd.	Aug., 1928	Abandoned at 4046 ft.
	El Zamuro 1	Standard Oil Co. of Venezuela	July, 1928	Abandoned at 4356 ft.
	Llanitos 1	British Controlled Oilfields, Ltd.	Sept., 1928	Abandoned at 3340 ft.
	Media 2	British Controlled Oilfields, Ltd.	Aug., 1928	Producer at 2210 ft. 200 bbl. 38° Bé.
	Media 3	British Controlled Oilfields, Ltd.	July, 1929	Drilling below 1895 ft.
	Vega Oscura No. 1	British Controlled Oilfields, Ltd.	April, 1929	Drilling below 2427 ft.
Democracia	Culebra 1	Richmond Petroleum Co.	Jan., 1929	Drilling below 4789 ft.
Miranda	Rio Seco 1	Creole Petr. Corpn.	Oct., 1929	Drilling below 3012 ft.
Merida:				
Libertador	Boscan 4	Venezuelan Sun, Ltd.	April, 1928	Abandoned at 5408 ft.
Zulia:				
Bolivar	Lagon 1	Venezuelan Gulf Oil Co.	May, 1929	Completed 12/15/29. Producer, 680 bbl., 16.2° A. P. I. Total depth, 4984 ft.
	LL 890	Lago Petroleum Corpn.	Aug., 1929	Completed 10/14/29. Producer, 212 bbl. 24.4° A. P. I. from near 3600 ft.
Colon	Los Manueles 3	Colon Development Co.	July, 1928	Drilling below 4171 ft.
	Rosario 1	Colon Development Co.	Jan., 1929	Drilling below 6850 ft.
Mara	Amboy No. 1	Venezuelan Gulf Oil Co.	June, 1928	Abandoned at 5316 ft.
	Calentura 1	Orinoco Oil Co.	Dec., 1929	Drilling below 1060 ft.
	Netick No. 1	Orinoco Oil Co.		Completed 4/14/29. Producer, 377 bbl. 28.7° A. P. I. at 5551 ft. Total depth, 5757 ft.
	Socuy No. 1	Soc. Française de Recherches au Venezuella	Nov., 1929	Shut down at 2185 ft. to abandon.
	Zuljy 1	Atlantic Refining Co.	Dec., 1928	Abandoned at 5180 ft.
Perija	El Leon	Rio Palmar	June, 1929	Producer at 1619 ft.
	Garcia 1	Creole Petr. Corpn.	Sept., 1928	Abandoned at 7102 ft.
	Garcia 2	Creole Petr. Corpn.	June, 1929	Abandoned at 3529 ft.
	Garcia 3	Creole Petr. Corpn.	June, 1929	Abandoned at 2270 ft.
	Neopod 1	California Petr. Exploration Co.	May, 1929	Drilling below 6854 ft.
	Peroc 1	Rio Palmar	Dec., 1929	Drilling below 1635 ft.
	Peron 1	Rio Palmar	July, 1929	Shut down at 3233 ft.
Sucre	Zulod 1	Soc. Française de Recherches au Venezuella	Sept., 1929	Drilling below 3109 ft.
	Zulom 1	Belgo Ven. Oil Co.	Dec., 1929	Drilling below 535 ft.
Urdaneta	Bajo Grande 1	Venezuelan Gulf Oil Co.	Nov., 1929	Drilling below 2727 ft.
	Bernal 1	Venezuelan Gulf Oil Co.	Dec., 1928	Abandoned at 5431 ft.
	Cacuz 1	Soc. Française de Recherches au Venezuella	Nov., 1929	Drilling below 3348 ft.
	Cahuz 1	Union Oil Co. of California	April, 1929	Abandoned at 6438 ft.
	Carmelo 1	Venezuelan Gulf Oil Co.	Sept., 1928	Abandoned at 5461 ft.
	Covir 1	Venezuelan Gulf Oil Co.	Aug., 1929	Drilling below 5720 ft.
	Ensenada 1	Venezuelan Gulf Oil Co.	June, 1929	Abandoned at 3996 t.
	Larrain 1	California Petr. Exploration Co.	March, 1929	Drilling below 5775 ft.

Eastern Venezuela

In eastern Venezuela an oil field is being opened up by the Creole Petroleum Co. at Quiriquire in the District of Piar, State of Monagas, which has the earmarks of being an important development. Ten or 12 oil wells have been completed and have proved up an area of several square kilometers. A potential production, estimated at 4000 bbl. per day of 19° A. P. I. gravity oil, has been developed, and preparations are being made to begin shipments of crude about the middle of 1930. The oil is reported to be found in the sands of the Llanos formation, Tertiary Age, under monoclinal conditions, and since the limits are as yet undefined, the area appears to have the possibility of becoming a major oil field. The Creole Petroleum Co. is building a pipe line to the San Juan River at Caripito, and is preparing to move out as much as 10,000 bbl. per day. Vessels of 20-ft. draft can reach the proposed loading piers.

Prospecting on West Shore of Lake Maracaibo

The west shore of Lake Maracaibo is being prospected with considerable thoroughness. The deep wells of the Gulf and Creole along the shore of the lake, and of the Gulf, Richmond, and Union farther inland have shown that throughout a large area in Urdaneta and northern Perija the Miocene oil-bearing formations are overlain by 5000 ft. or more of unproductive Maracaibo and Puerta beds. There still remain possibilities for production on anticlinal structure in the underlying Eocene and older formations, but the Miocene possibilities appear less favorable than is the case in the Bolivar Coastal district. Prospect drilling is being actively carried on by several companies, and interesting developments may be anticipated during 1930.

In the District of Mara, the Netick No. 1 of the Orinoco Oil Co., in which oil was discovered in 1928, was finally completed as a 377-bbl. producer in April, 1929, with a total depth of 5551 ft. The oil has a gravity of 28.7° A. P. I. and is said to be coming from a formation of lower middle Eocene Age, which is the probable equivalent of the Misoa. Two wells have been abandoned at depths below 5000 ft. and two new tests are now drilling.

DISCUSSION

C. P. Watson,* Fort Worth Texas.—It seems rather significant that every paper dealing with production[1] has shown a surplus and a large potential reserve.

H. J. Wasson,† New York, N. Y.—There is little to be added to Mr. Estabrook's informative paper. I agree with Mr. Watson that our concern regarding oil shortage is being allayed with each new area that is discussed.

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* President, Federal Royalties Co., Inc.

[1] In this volume.

† Consulting Petroleum Geologist.

Fig. 1 brings out facts concerning the rate of drilling necessary to obtain this production. There is a great tendency on the part of many domestic operators to assert that the "wild scramble for production in Venezuela" is really the source of all troubles here in the United States. If curtailment could be measured in terms of

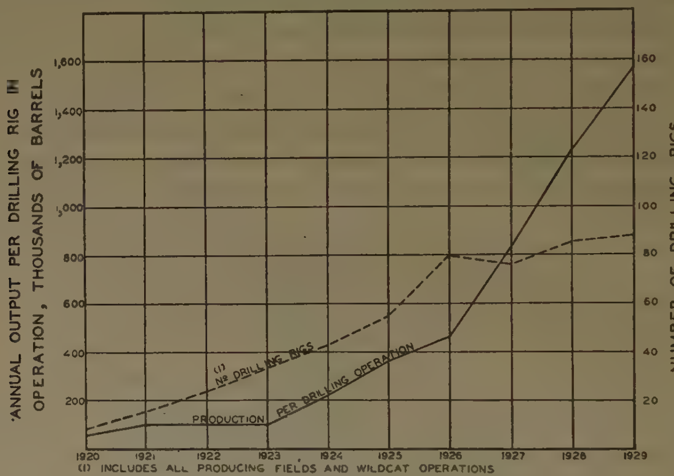

Fig. 1.—Average number of drilling rigs operating in Venezuela and annual production per rig.

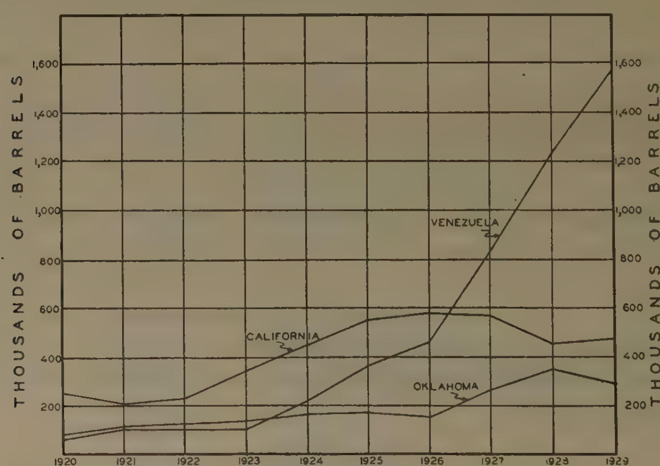

Fig. 2.—Annual production per drilling operation.

drilling operations instead of in terms of barrels, this viewpoint could be shown to be highly erroneous. I do not say that it is entirely sound to measure the rate of curtailment by the rate of drilling, but the two are certainly functions of each other, and I think you will be surprised to see what the rate of drilling is in Venezuela.

The dotted line in Fig. 1 indicates the average number of drilling rigs in active operation during each year, from 1920 to 1929. It includes all drilling wells in producing fields and about 20 wildcat operations that have been in constant progress. Starting in 1920 at approximately 10 rigs, the number increased steadily to 1926

when there were 80 rigs in the country. There are probably 15 or more companies in the United States that have more than that number working for an individual account.

The solid line gives an index of what drilling activities of that magnitude can accomplish in the way of producing oil. The figures for this curve were obtained by dividing the annual production by the number of rigs in operation during the year. There was not much change in the curve while the Mene Grande field was the only one producing; then La Rosa caused an increase in 1924 and the rapid increase since 1926 is the result of development of prolific wells in the Lagunillas field. In 1929 the production for the country averaged about 1,600,000 bbl. per drilling operation. It is hard to conceive of companies having such large investments as those in Venezuela conducting drilling operations on a much more limited scale. In other words, these reports of competitive drilling are grossly overstated. Fig. 2 shows for comparison the annual production for each drilling operation in Venezuela, Oklahoma and California.

E. L. Estabrook, New York, N. Y.—You may be interested in some drilling data from Venezuela. The formations are very soft, and some remarkable records on completion time have been made. For instance, we complete wells up to 3000 ft. deep in less than 15 days, including time for cement to set; 4000-ft. wells are completed in only a few days more than that. We have drilled as much as 2500 ft. without coming out of the hole.

Russian Oil Fields in 1928 and 1929

By Basil B. Zavoico,* Tulsa, Okla.

(New York Meeting, February, 1930)

Considerable progress has been made during the past year throughout the Russian petroleum industry. Perhaps the most remarkable achievement is the execution of the programs set out by the Central Planning Bureau of the Department of Commerce. These programs have been increased twice during the past operating year, necessitating drilling the richest reserves, instead of developing gradually as originally planned. The fulfillment of the set-out programs during the past few years makes therefore the present five-year plan of considerable importance to the international oil statisticians in approximating actual supply conditions up till 1933.

The production of all Russian fields increased by 14,200,000 bbl. as compared with the 1927–1928 operating year, while the next year's program anticipates a further increase of 15,700,000 barrels.

Table 1.—*Russian Petroleum Production by Fields*

Millions of Barrels

	1916	1922–23	1926–27	1927–28	1928–29	1929–30 Estimated	1932–33 Estimated
Baku	55.81	25.30	49.00	54.15	62.1	71.4	78.5
Grozny (incl. Kuban)	12.73	10.90	22.79	26.50	32.4	37.8	38.4
Emba	1.82	0.97	1.83	1.82	1.86	1.95	
Turkestan	0.44		0.21	0.26	0.26	0.50	
Saghalien	None	None	None	None	0.23	0.68	
Oural	None	None	None	None	None	0.14	
	72.80	37.17	73.98	82.60	96.80	112.50	187.00

It appears therefore that production for 1932–33 will total 187,000,000 bbl., or approximately double that of the operating year just closed. It is also evident that the old fields are counted upon to produce only about 67 per cent. of the total, the new fields, not yet discovered, to furnish the balance of 33 per cent.

The Soviet oil leaders therefore are hoping to have new fields discovered and developed by 1932–33. However, as in the past wildcatting

* Consulting Geologist.

has been distinctly without positive results, and new field development is extremely slow, the relative importance of 1932–33 figures will be changed, but the total production planned for 1932–33 will most likely be obtained, and as a matter of fact could be increased without new discoveries. The Baku fields alone, if actively developed, probably could produce 150,000,000 bbl. by 1932–33. The presently producing Grozny fields could not add much to planned production, but the Maikop Division of Grozneft can supply much oil near Touapse, the new export and refining port on the Black Sea. It is evident that with the development of older areas gaining momentum, the discovery of new major fields is absolutely necessary. Such major pools must be opened before or during 1933, so as to contribute large production during 1934, otherwise the undersupply of petroleum in Russia will reach alarming proportions by 1935. The undeveloped petroleum reserves are very rich in several districts of Russia, according to cumulative geological evidence, and therefore more practical and more thorough wildcatting is the imperative requirement of the day.

Baku—Azneft

The fields of the Apsheron peninsula continue to be the richest area in Russia, and, although they have been in active development for more than 50 years, they promise not only to surpass all previous producing records, but to maintain a very large output for many years to come.

The total production of the Baku fields from 1880 to July 1, 1929, was 2,000,000,000 bbl. from an area equal to 6,170 acres, or an average recovery per acre of 324,000 bbl.; this, however, includes two relatively new fields, the Surakany and the Bibi-Eibat Bay Extension. The old area of Balakany-Sabunchi-Ramani, now called the Lenin Division, covering 3,700 acres, reached an average recovery per acre of 378,000 bbl.; the Bibi-Eibat field proper, covering 615 acres, reached an average recovery per acre of 580,000 bbl., while the relatively newer Surakany field has so far recovered 248,000 bbl. per acre on 1,370 acres and the recently opened Bibi-Eibat Bay Extension only 56,000 bbl. on its 300 acres. Undrilled acreage held in reserve and considered as proved is composed of 1,300 acres in the old area, 250 acres in Bibi-Eibat and 630 acres in Surakany. The recently opened Kara-Choukour extension to Surakany field will probably cover about 2000 acres. Therefore it becomes at once apparent how large are the reserves of the older Baku fields alone.

The real conception of the actual reserves, however, requires examination of fields individually. In Balakany-Sabunchi-Ramani fields only the Balakany subdivision is producing from the full section of the "Oil Measures" of the Pliocene, including the lowermost Kirmaku

horizons, and even in Balakany large tracts are still undrilled to Kirmaku. During last operating year the Sabunchi subdivision gave very large gushers from Kirmaku horizons, with development of these sands just beginning. In Ramani subdivision Kirmaku horizons are yet untested, but the presence of very rich reserves in them is unquestionable. In Bibi-Eibat field proper even the formations above the Kirmaku are just touched; the deepest sand horizon, the sixteenth, was opened during 1929, giving gushers with initial output of 14,000 bbl. per day from 3500 ft.; the Kirmaku horizons in Bibi-Eibat are still undrilled, but in all probability should be most prolific. The Bibi-Eibat Bay Extension is in preliminary development only, less than half of the "Oil Measures" above the Kirmaku being developed so far. Finally, the Surakany field last year saw the active development of the fifth horizon of the Middle "Oil Measures" which proved to be exceptionally rich, and but two wells sunk to the sixth horizon are producing 10,500 bbl. and 8000 bbl. per day each at 3000 ft. There is no reason why the Lower "Oil Measures," including the Kirmaku, should not prove most prolific in Surakany. The Kara-Choukour extension of Surakany is producing from its first well 4000 bbl. per day from the Middle "Oil Measures," with the extremely rich portion of the "Measures" still untested.

In addition to the "Oil Measures" of Pliocene, the Miocene and Oligocene formations have oil in outcrops and, therefore, should show at least some kind of saturation in the present fields, though it may be necessary to drill to 5000 ft., or even 7000 ft., to reach the Oligocene. The present average depth of new completions in Baku probably does not exceed 2750 feet.

Of slight importance at this time in the Baku area are the following potential districts; the Puta, initial production up to 700 bbl.; the Sulu-Tepe, initial production up to 50 bbl.; the Khan-Kishlak, initial up to 150 bbl., and the Chail-Dag with an initial production up to 150 bbl. Any of these districts may develop large fields upon deeper drilling.

The total footage drilled in Baku fields in 1928–29 was 1,050,000 ft., as compared with 860,000 ft. during the previous operating year. The 1929–30 program calls for 1,300,000 ft. to be drilled, while the 1932–33 plan anticipates a total of 1,650,000 ft. During 1928–29 rotary rigs made 915,000 ft., the cable rigs 102,000 ft. and the turborotaries 34,000 ft. Drilling for production totaled 995,000 ft., while wildcatting claimed 55,000 feet.

The total production of Baku fields during 1928–29 was 62,100,000 bbl., an equivalent of 170,000 bbl. per day. Of this amount flowing wells contributed 28.8 per cent., pumping wells 36.0 per cent. and air-gas lift installations 28.9 per cent. At the end of the 1928–29 operating year the daily average production in Baku was 188,000 bbl. from 3567 wells, or an average per day per well of 53 bbl. The

Surakany field produced 38.4 per cent. of the total (67,000 bbl. per day), and the Bibi-Eibat field 21.4 per cent. The 1932–33 program calls for 50 per cent. of the total Baku production to be derived from Surakany field.

The labor situation in Baku remains without notable improvements, the number of workers still reaching a total of 45,000 men. The average pay per man per month increased to $45.75 from $41.60 during the preceding year.

Grozny—Grozneft

The two Grozny fields, the New and the Old, are both in routine development. No new sands were discovered, and the production is to be maintained at the present levels by forced development of richest horizons, the XIIIth, XVIth and XXIst. The wildcatting in the Grozny district did not result in opening major pools, though their presence is practically certain. Geophysical methods of reconnaissance are being employed and new fields may be expected to be brought in during the next five years, when actual subsurface conditions will be correlated with the geophysical surveys. A considerable difficulty may be encountered in continuing wildcatting because the majority of the new fields in Grozny district will be located north of the present fields and away from the mountains with the required depth most likely in excess of 4000 and 5000 ft., entirely too deep and too expensive wildcatting for an organization unaccustomed to deep drilling, and not acquainted as yet with the necessarily large proportion of dry holes, particularly so in an area entirely unknown structurally (covered by recent deposits), even though the best of geological service is available.

The total footage drilled in Grozny districts amounted to about 300,000 ft., the 1929–30 plan calling for 400,000 ft. The necessity of new discoveries is emphasized by the fact that fully 25 per cent. of the total footage during 1929–30 is to be made in wildcat areas. Rotary rigs predominate in Grozny.

During 1928–29, fully 74 per cent. of the total Grozny production was recovered from naturally flowing wells, while the next year's plan increases that proportion to 80 per cent. A total of 58 flowing wells will be in production during 1929–30, furnishing 28,000,000 bbl., or an average in excess of 1300 bbl. per day per well. The balance of production is to be obtained from 591 wells, mostly pumpers. The total number of producing wells during 1928–29 operating year was 599.

Kuban—Grozneft

In Maikop district very large gushers of light oil have been brought in from the "C" sand horizon. The discovery well (No. 46, parcel 121, group 433) did 25,800 bbl. of 34° Bé. oil during its first 24 hr. from the total depth of 2040 ft. A total of six producers was completed in

"C" horizon furnishing 600,000 bbl. during 1928–29 operating year. Such relatively small production was due to complete lack of storage and transportation facilities in the field, the wells being open only periodically. The actual importance of the discovery is not as large as the initial output would indicate, all sands in Maikop being very lenticular and carrying much water. However deeper possibilities of the area are great, but it will take some time before even 4000-ft. tests will be drilled.

Emba—Embaneft

Routine development and shallow wildcatting, without any notable discoveries, took place during 1928–29. Geophysical instruments were being used extensively in locating additional salt domes.

Northern Saghalien—Saghalienneft

Saghalien Island entered the list of producing areas of the world during the past year and at this time the future of the oil industry on the island appears assured. A total of 230,000 bbl. was produced during 1928–29 from Russian properties, next year's plan anticipating 860,000 bbl. The Russian Government at the end of the year had 11 producing wells and 4 drilling, the producing wells averaging about 100 bbl. per day. While only the fourth horizon at 650 ft. was in development at that time, with initial production ranging from 70 to 250 bbl. per day, a deeper discovery was made at the close of the year, named the fifth horizon, the wells having initial production of 550 bbl. per day from 950 ft. So far, two Japanese and one Russian wells have been completed in the deeper pay. Very likely Saghalien Island production will assume major proportions when wells are carried to greater depths, thus affecting the whole structure of the Far-Eastern petroleum markets.

Oural—Ouralneft

A very important regional discovery was made not far from Perm, west of the Oural Mountains, while drilling for potash. The discovery well made some commercial oil from porous dolomitic limestone underlying Permian salt, gypsum and anhydride beds, a geological condition similar to the Southwest Texas and Persian fields. An ambitious development program has been launched, because of the accessibility of the new area to the Volga River navigation system and its proximity to the rich mineral resources of the Oural Mountains.

Pipe Lines

The Grozny-Touapse (on the Black Sea) pipe line, completed during the last year, will have its capacity increased to 12,000,000 bbl. by adding

five pumping stations. The new Baku-Batum 10-in. line is being built; its completion has been delayed 12 months, full operation accordingly not starting until 1931. The pipe line from the Caspian Sea to Moscow has been authorized and at this time its routing is being planned and surveyed. In conjunction with this line the Government Oil Trust plans to build a refinery in Moscow with a capacity of 6,000,000 bbl. per year. Both projects will not be completed until 1932–33 operating year.

Refining

During 1928–29, 77,500,000 bbl. were run to refineries (81.1 per cent. of total production), as compared with about 63,000,000 bbl. in the preceding year. The 1929–30 operating year anticipates a very large increase in total runs, the refineries taking 96,000,000 bbl., or 87.2 per cent. of the planned production. The increases are falling principally on new refineries now being completed in Batum and Touapse, both on the Black Sea.

Gasoline recovery showed some improvement, reaching 7 per cent. of total runs of Baku crudes and 16.6 per cent. of Grozny crudes; kerosene recoveries were respectively 25 per cent. in Baku and 17 per cent. in Grozny.

Table 2 shows total production of refined products in the Soviet Union in 1928–29, as against the planned figures for 1929–30.

Table 2.—*Total Production of Refined Products in Russia*

Product	1928–29, Bbl.	1929–30, Bbl.
Gasoline	10,100,000	14,000,000
Kerosene	18,600,000	23,500,000
Lubricating stocks	3,050,000	3,550,000
Fuel and other special heavy oils	43,800,000	53,500,000

Marketing

The distribution of petroleum products continued to increase greatly in excess of anticipated figures. Total exports increased 29 per cent. in 1928–29, as compared with 1927–28, while the total home market consumption increased 14.9 per cent. in the same period of time. Percentage increases by products and by markets are shown in Table 3.

In the interior markets the consumption of kerosene exceeded the planned figures very considerably, causing at one time slowing up of deliveries as well as lowering of quality; to some extent the export of kerosene was also curtailed. This demand has been due primarily to the use of tractors, but the general stabilization was an important factor. Consumption of gasoline in the country continues at very small figures,

the total for 1928–29 being 1,100,000 bbl., about 1 day's requirement in U. S. A. The planning bureaus of the Soviet Union are anticipating the growth of home consumption at figures prevalent in other countries of the world, while in reality any improvement in the interior of any consequence at all may very well result in doubling and trebling the demand in the course of 1 to 2 years, provided the increased amounts could be put on the market.

The exports are being continuously pushed in order to provide foreign currency for purchases of machinery and other manufactured goods. The export of gasoline is, of course, necessary because the demand at home is negligible. According to plans most of the future exportable products will be refided in Batum and Touapse refineries located on the Black Sea.

TABLE 3.—*Increases in Deliveries of Refined Products in* 1928–29, *as against* 1927–28

Products	Home Markets, Per Cent.	Exports, Per Cent.
Fuels	10.9	36.4
Kerosene	32.1	8.0
Gasoline	35.9	32.0
Lubricating Oils	17.8	14.8
Total	14.9	29.0

OUTLOOK OF THE RUSSIAN PETROLEUM INDUSTRY

The brief survey of the present position of the oil industry in Russia indicates that the lack of proved reserves is alarming even at this time. This is particularly true if one considers the length of time necessary in Russia to develop a new field. While the present pools will supply sufficient production for the next 2 to 3 years, a major industry, like petroleum, should have at all times open reserves of raw material for at least 5 to 10 years, otherwise the dependent industries would not be justified in spending capital on machinery using petroleum products, thus retarding the growth of consumption, and in the end affecting the development of the country. Therefore the discovery of new major pools in Russia is at this time of primary importance.

DISCUSSION

D. C. BARTON,* Houston, Texas.—I would like to suggest the interesting potentialities of salt-dome production at the head of the Caspian Sea. Salt domes are known in that vicinity—the Dossor dome produces over 1,000,000 bbl. per year—and there is a vast coastal plain there about which little is known geologically. The Soviet Government has done enough geophysical work to show that some of the domes are very extensive.

* Consulting Geologist and Geophysicist.

B. B. Zavoico.—The reserves in Russia are tremendous, but it is difficult for an organization not accustomed to drilling deep holes to be persuaded to do so. It will be necessary to drill 4000 and 5000-ft. holes, and, at the very best, only one out of 10 to 20 wildcats will be productive, because the regional subsurface is, as yet, practically unknown. At present the management wants every wildcat to be an oil well, and if the wildcats are not productive, reasons for the absence of commercial production must be stated in detail. It is considered that geologists are wasting the money in drilling dry holes.

H. J. Wasson,* New York, N. Y.—Is there any possibility of getting a comparison of cost data?

B. B. Zavoico.—The actual cost of the oil is surprisingly high, because of the present inefficiency of methods and high labor costs, due to small productivity per labor unit.

In the United States a production of 250,000 bbl. per day certainly could be taken care of by a maximum of 10,000 men. In Baku and Grozny alone, 60,000 men were directly employed in the oil industry, getting an average wage of 50 rubles per month, a ruble, for all purposes, being equal to a dollar (or even to two dollars) in the Russian oil fields, so if you consider the productivity of labor per unit of money it will be very considerably higher in the United States than it is in Russia. And another thing is that in this country we can consider any industry as an individual factor, the oil industry not being obliged to take care of any other industry. In Russia the oil industry is the only industry that has much exportable products readily available, so it has to support every other industry in the country that cannot pay for itself (speaking in terms of foreign currency, of course), and there are not a few of them. In other words, the oil industry covers the export and import deficit balances of other industries.

H. J. Wasson,—Have we anything to fear from an influx of oil from Russia?

B. B. Zavoico.—The present plans call for 250,000,000 bbl. to be produced during 1933. The home consumption is primarily kerosene for tractors and fuel oil for general industrial use. The consumption of gasoline in Russia per year is equivalent to a little less than one day's requirement in the United States. New tractors are the only thing that will use gasoline in large quantities. The peasants often use cheaper vegetable oils instead of kerosene for lighting. The question of future consumption depends entirely on the policies the government will adopt. If the present plans for communizing the peasants meet with considerable success, as some people think they will, consumption will increase tremendously. If not, the rate of increase will be very slow. Even if the 1933 estimates of 250,000,000 bbl. of total production are reached, the amount of gasoline will probably reach one-quarter of that figure. By that time Russia will have a fair gasoline consumption of its own, but, even so, at least 50,000,000 bbl. of gasoline could be exported from Russia in 1933, if the indicated production is achieved. As much or more fuel oil also will be exported. The danger lies not in the amount that the Soviets can export, but in their ability to undersell all competitors, due to their form of government. Thus a minor percentage of petroleum products can entirely demoralize the European markets. However, such demoralization would harm the Soviets as much as anyone else, so according to present indications, the Soviets will cooperate in maintaining the price.

E. R. Lilley,† New York, N. Y.—Is not that proof that the cost of production is low—that they have profit to give to other industries?

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* Consulting Petroleum Geologist.

† Associate Professor of Geology, New York University.

B. B. Zavoico.—There are two ways to look at it—what they are getting for oil in dollars and what they are paying for it in rubles. The official international exchange and their private exchange are two different things. They are paying the workers, say, 50 rubles a month, and on the Soviet Government exchange it is equivalent to $25, while in Europe it is possibly $15, or even less. That is where the Soviet Government gains. After all, the production cost in a socialistic government is an abstract figure. The selling price of various exportable goods is a net income profit in foreign currency to the Soviet Government, so that even at 1 c. per gal. sold on European markets the Soviet Government would be making exactly 1 c. profit. It is to their advantage to obtain the maximum possible price; hence the selling agreements with the British and American marketing groups. If the Soviet Government succeeds in its industrial policies, it will feel much stronger in its foreign trade, and because of the anomalous position between a socialistic government and the capitalistic ones, it may become imperative for Europe to levy prohibitive tariff on anything exported from Russia to protect their home industries from this peculiar situation.

F. O. Martin,* Los Angeles, Calif. (written discussion).—From observations made during a recent visit to some of the Russian oil fields and from studying economic conditions in European Russia and in Sibera, I fully concur with the author that the discovery of new major pools in Russia is of primary importance. A ccording to the plans made by the Soviet Government for agricultural development on a large scale and for more industrial development, it is evident that Russia itself will consume more petroleum products, while at the same time it will need more money to finance these projects and the money again must come from increased exports of petroleum products.

It is the consensus of all petroleum geologists, of whom I have heard and who have been in the Caucasus region, that many more oil fields may yet be discovered there. All it needs is more detailed geological work. The same may be said of the Ural Mountains and of those mountain ranges north of Afghanistan. As far as Siberia is concerned it may still be called a closed book. Oil seepages have been reported from many places, but only in Kamtschtka, as far as I know, has detailed geological work referring to oil deposits been done. If present Government conditions continue such geological work will be done on a small scale, because it appears to me that the Government pays more attention to the already insured production of existing fields.

* Geologist, Union Oil Co. of California.

Mexican Oil Fields during 1929

By Valentín R. Garfias* and C. O. Isakson,† New York, N. Y.

(New York Meeting, February, 1930)

The production of oil in Mexico during 1929 was approximately 45,000,000 bbl., or 5,000,000 bbl. less than in 1928. The production of the fields near Tampico showed a decline of over 10,000,000 bbl. for both the light and heavy crudes, which was partly offset by an increase of over 5,000,000 bbl. in the production of the fields in the Isthmus of Tehuantepec.

During 1929 the retrenchment policy followed by practically all the companies was continued and no material improvement should be expected until the unsatisfactory conditions that brought about this situation are remedied. A new administration has just assumed control in Mexico; it should remain in power for 6 years, and the progress of the oil industry during that time will depend primarily on the policy pursued by the new government with respect to oil development.

Development

During 1929, there were drilled 214 wells as compared with 371 in 1928 and 583 in 1927. The percentage of producers in 1929 was 47.2 as against 34 per cent. in 1928. The new wells did not show water as quickly as in 1928, particularly in the Cacalilao field, where the greatest number of producers was brought in, their average initial daily production being 380 bbl. The flush daily production per well in the Southern fields was 1730 bbl., while the wells in the Isthmus of Tehuantepec came in with an average of 770 bbl. Development is summarized in Table 1.

In the Southern fields 63 wells were drilled in 1929, of which 23 were producers, the best being drilled in Paso Real. This development tends to show that the southern extension of Dos Bocas-Alamo fault from Alamo to San Isidro terminates at San Isidro.

The two wildcat wells completed in 1929, one in Magiscatzin and the other in Xicotencatl, were failures, and at the end of the year there were eight wildcat wells drilling and material was being hauled for two more.

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† Agent, Foreign, Department Henry C. Doherty & Co.

TABLE 1.—*Petroleum Development in Mexico,* 1929

	Failures	Producers	Total
Northern Fields			
Panuco	23	12	35
Topila-Caracol	10	9	19
Chapacao-Corcovado	7	1	8
Salinas	3	2	5
Cacalilao	17	15	32
Limón	0	0	0
Altamira	2	0	2
Quebrache	1	0	1
Total	63	39	102
Southern Fields	40	23	63
Isthmus of Tehuantepec	8	39	47
Wildcats	2	0	2
Total	113	101	214

PRODUCTION

Table 2 shows production in 1929, as compared with that of the previous year. The production in the northern fields during 1929 declined steadily in all pools from 57,300 bbl. daily in January to 48,300 in December, the daily average per well in January being 114 and in December 82 barrels.

TABLE 2.—*Petroleum Production in Mexico,* 1928 *and* 1929

Fields	1928, Bbl.	1929, Bbl.	Increase, Bbl.	Decrease, Bbl.
Northern (12° Bé.)	25,404,000	20,200,000		5,204,000
Southern (21° Bé.)	21,973,000	16,500,000		5,473,000
Isthmus of Tehuantepec (32° Bé.)	2,773,000	8,300,000	5,527,000	
Total	50,150,000	45,000,000		5,150,000

Production in the southern fields increased 45,000 bbl. daily in January to 49,000 daily in December, due to the bringing in of some good wells at Paso Real on the Alamo-San Isidro extension of the fault.

The most important development was recorded in the Tehuantepec fields, production having increased from approximately 7000 bbl. daily at the beginning of the year to about 35,000 bbl. in December. From present indications this production will be maintained easily and prob-

ably increased during 1930. Considerable activity during the year took place in the northeastern part of the Isthmus, resulting in the discovery of the Tonalá field, which promises to surpass the other producing areas in Tehuantepec (Fig. 1).

FIG. 1.—TEHUANTEPEC FIELDS.

OIL IN STORAGE

Oil stocks in Mexico increased about 1,500,000 bbl. during 1929, mostly in heavy crude. Table 3 shows the total amount of oil in storage on Jan. 1, 1930, as compared with Jan. 1, 1929.

TABLE 3.—*Mexican Oil Stocks, Jan.* 1, 1929 *and* 1930

	Jan. 1, 1929, Bbl.	Jan. 1, 1930, Bbl.
Heavy crude (12° Bé.)	6,500,000	7,550,000
Light crude (21° Bé.)	1,700,000	1,850,000
Topped (17° Bé.)	5,700,000	5,850,000
Refined products	900,000	1,000,000
Total	14,800,000	16,250,000

EXPORTS

Total exports for 1929 were approximately 28,000,000 bbl., a decrease of 8,000,000 bbl. from 1928. Of this decrease 2,000,000 bbl. was in heavy crude, 3,000,000 bbl. in fuel oil, 1,000,000 bbl. in light oil and the rest in bunkers and distillates. Exports to the United States amounted to 19,000,000 bbl. Only six marine terminals were in operation during the year. Exports in 1929 are shown in Table 4.

TABLE 4.—*Exports of Mexican Petroleum by Grades*, 1929

	Barrels
Heavy crude (12° Bé.)	15,743,000
Fuel oil (17° Bé.)	3,762,000
Light crude (21° Bé.)	
Distillates[a]	5,427,000
Asphalt	1,706,000
Bunkers	1,106,000
Total	27,744,000

[a] Includes 1,588,000 bbl. of gas oil.

TABLE 5.—*Mexican Oil Tax Rates, September*, 1928 *and* 1929

Grade	Taxes, Dollars per Barrel	
	September, 1928	September, 1929
Heavy crude (12° Bé.)	$0.14	$0.14
Light crude (21° Bé.)	0.22	0.22
Fuel oil (17° Bé.)	0.19	0.19
Gas oil	0.28	0.28
Refined gasoline	0.27	0.25
Crude gasoline	0.54	0.51
Refined kerosene	0.16	0.15
Crude kerosene	0.30	0.30
Lubricants	0.29	0.29

TABLE 6.—*Taxes Paid to Mexican Government on Oil Exported*

Year	Taxes	Year	Taxes
1920	$ 22,740,000	1925	$ 21,072,000
1921	31,562,000	1926	17,411,000
1922	42,990,000	1927	9,512,000
1923	30,268,000	1928	5,633,000
1924	27,311,000	1929 (estimated)	4,311,000
		Total	$212,810,000

TAXES

A new tax law went into effect in January, 1930. Based on the present prices of bunker oil, this results in a nominal reduction in taxes while the new tariff law, which likewise went into effect in January, 1930, places duties on oil-well and refinery material ranging from ½ to 2 c. per pound. These new import taxes in general are considerably higher than the former consular invoice tax of 5 per cent. net ad valorem, which has been abolished.

Table 5 gives the taxes on oil exported, while Table 6 gives the total yearly export taxes paid to the Mexican Government since 1920. High as the present taxes are in comparison with the market price of the crudes

(the price of Panuco crude has dropped about 50 per cent. while the tax remains practically unchanged) the aggregate amount collected by the government in 1929 was only about 10 per cent. of the total collected in 1922.

Outlook for 1930

The outlook for 1930 for the fields near Tampico is not encouraging and there is no likelihood of new fields being discovered during the year, as the companies do not feel justified in starting extensive exploratory work under present conditions.

The Mexican oil industry should continue during 1930 the general trend of the previous year; the gradual decline in the production of the fields near Tampico is to be expected as well as a moderate increase in the production of the fields in Tehuantepec. The over-all decline should be about the same or possibly less than during the previous year and the production for 1930 should, therefore, approximate somewhat in excess of 40,000,000 barrels.

Petroleum Production in Dutch East Indies and Sarawak (Western Borneo) in 1929

By J. Th. Erb,* The Hague, Netherlands

(New York Meeting, February, 1930

The total crude oil production of these islands, which in 1928 amounted to nearly 5,000,000 metric tons—about 36,500,000 bbl.—has again increased in 1929. The figures for 1929 are as follows:

	Metric Tons†
North Sumatra	369,930
South Sumatra	1,236,510
Java and Ceram	678,787
Dutch Borneo (including Tarakan)	2,793,326
Sarawak	759,700
Total	5,838,253

† 1 metric ton = 7.36 bbl. on the average.

This production, as far as the Dutch Islands are concerned, is owned partly by the Bataafsche Petroleum Maatschappij, the producing subsidiary of the Royal Dutch Petroleum Concern, and partly by the Koloniale Petroleum Maatschappij (Standard Oil Co. of N. J.), while that of the British Protectorate Sarawak belongs to the Anglo-Saxon Petroleum Co., Ltd., of London.

The increase in 1929 is due partly to more intensive drilling; the rotary system, which enables drilling to be done more quickly and to greater depths than was possible with the percussion system, has come into more general use. Further, considerable extensions have been made to some of the existing fields and several new pools have been discovered, which contributed in no small degree to the increase in production.

Of particular interest is the fact that the "Niam" (Nederlandsche Indische Aardolie Maatschappij), in which the Dutch Government has a large share and which company in 1928 was producing from only two fields in South Sumatra, has discovered a pool in North Sumatra and, moreover, has struck oil on the island of Poeloe Boenjoe near Tarakan (Eastern Borneo).

The deepest well still drilling is in one of the fields of the "Niam" and has reached a depth of 2269 meters (7445 feet).

Notwithstanding the tropical climate and the dense jungle in which most of the fields are situated, the most modern scientific methods are applied in exploration, in drilling, producing and refining.

* Director, Royal Dutch Petroleum Co.

Petroleum Production in Rumania in 1929

(Special Correspondence)

(New York Meeting, February, 1930)

On the map of Europe the shield-shaped area included in the boundaries of Rumania appears too small to constitute a very important factor in the world's oil production. The country has a total area of 122,000 square miles of territory, about one-fifth of 1 per cent. of the world's surface, from which about 2½ per cent. of the world's oil was produced in 1929. This relatively small area also constitutes one of the known billion-barrel reserves of the world.

Oil has been found in various localities in the foothills of the Carpathian Mountains, extending more than 100 miles in length at their base. It is rather unusual that, while the extent of prospective territory seems to be large, the area of the commercially productive pools is comparatively small.

Oil accumulation in Rumania is closely associated with salt stocks. Shows of oil are encountered from the Pliocene down to the Cretaceous. Most of the production, however, comes from the Pliocene, the chief producing sands of which are the Dacic and the Meotic, although some oil is produced from the Levantic and the Pontic. The Meotic as a source of oil was known for many years, but the intensive output from this sand series is a comparatively recent development and accounts in a big measure for the steady increase in Rumanian production.

In the early part of the summer of 1929 the Astra-Romano (Royal Dutch) completed a well at Moreni in what is thought by some to be a fourth Meotic sand (a new sand series) at a depth of 5200 ft. with an initial production of 2000 bbl. a day of 41° gravity oil. The development of this new horizon has been somewhat retarded by the disastrous fire which occurred at Romano-Americana's well No. 160 in Moreni, but its discovery adds materially to the future life of the Moreni area, one of the country's oldest fields.

Rumania's production for 1929 is estimated at 35,556,000 bbl., a daily average of 97,400 bbl. This compares with the total of 31,542,000 bbl. for the previous year, a daily average of 86,180 bbl., or an increase of 12.73 per cent. Rumania now occupies seventh position in the world's oil picture, it having been replaced as the sixth in importance by the Dutch East Indies in 1929. Table 1 shows a comparison of production by districts and fields.

Table 1.—*Production of Petroleum in Rumania by Districts*, 1928–1929

	1928, Bbl.	1929,* Bbl.		1928, Bbl.	1929,* Bbl.
Prahova:			*Dambovitza:*		
Moreni	11,704,533	11,711,738	Ocnitei	4,633,419	4,454,367
Chiciura-Gropi-Tontesti	2,840,258	4,045,454	Ochiuri	3,263,801	3,720,386
Runcu-Scorteni	1,868,103	1,743,147	Gorgota	39,766	203,779
Bustenari-Calinet-Grausor	767,134	725,871	Others	2,808	2,071
Ceptura	2,773,726	4,929,757	Total	7,939,794	8,380,603
Tintea	859,317	651,566	*Buzau:*		
Baicoi	653,646	610,688	Arbanasi	779,682	595,020
Campina	521,808	547,843	Sarata	51,782	39,418
Piscuri		714,114	Total	831,464	634,438
Others	264,362	277,968	*Bacau:*	517,844	583,201
Total	22,252,887	25,958,146	Total Rumania	31,541,989	35,556,388

* One month estimated.

The increase in production is practically all accounted for in the District of Prahova (see Table 1), which produces over 70 per cent. of all the Rumanian crude. Ceptura, which is a comparatively new field, having passed the million-barrel mark in 1928, had considerable new prospective territory added during 1929, and there are good prospects here for deeper horizons in the Meotic. The Piscuri field, a new one in the producing list in 1929, is an eastern extension of the Moreni area. The production from this field is coming from the Drader sands, and prospects for deeper production in the Meotic are excellent.

The only other new discovery of importance was at Boldesti, also in the District of Prahova. Previous to the completion of Astra-Romana's No. 7 in October, 1929, the Boldesti field produced only gas from the Dacic sands. The Astra's well was completed at 5520 ft. in the Meotic good for 882 bbl. a day.

A significant development in Rumania during 1929 was the change in the 1924 Mining Law, which provided that Government oil lands would be granted for development only to nationalized companies. The new Mining Law passed in March allows foreign capital to compete for state lands. However, there are still many objectionable features to the new law which, coupled with the numerous taxes imposed, high royalties and increased cost to drill and produce from deeper sands, are discouraging to the prospective investor.

Review of Colombian Operations in 1929

By Michael O'Shaughnessy,* New York, N. Y.

(New York Meeting, February, 1930)

The outstanding features of the Colombian situation for the year 1929 were legal and political. The passage of Law 84 and the promulgation of the Regulatory Decree 150 were recounted in the review for 1928, as was also the Presidential proclamation suspending this law and its accompanying decree until decision could be reached in the suits filed against them before the Supreme Court and the Council of State.

Early this year the Minister of Industries, José Antonio Montalvo, announced the appointment of a commission of foreign experts to aid in drafting a new petroleum law. He requested all of the foreign experts employed not to consult with the oil company representatives in Bogota, and these experts were therefore shut off from receiving any suggestions from those who had actually operated in the country and knew the conditions under which operations would take place. It was to be expected that the provisions of a law suggested under such circumstances would not meet operating conditions satisfactorily. The specific objections are stated in *O'Shaughnessy's South American Oil Reports* (April, 1929).

An especially qualified commentator observes that one of the curious provisions of the proposed law was the high royalty on gas—5c. per 1000 cu. ft. of gas produced. There was also a provision requiring 20 per cent. of the stock of the company operating in Colombia to be offered for sale to Colombians. The bill failed to pass Congress in the closing hours of the session. The Supreme Court, in the meantime, handed down its decision on Law 84 of the previous year and Regulation 150 covering the enforcement of that law. Contrary to expectation, the majority opinion of the Court practically affirmed the constitutionality of both the law and the regulatory decree, with the exception of Article 20 and parts of Article 21 of the decree which referred specifically to the registration of private properties.

At the time the suit was filed against Law 84 and Decree 150 the operation of these measures was suspended by the Executive. Law 84 and its Regulatory Decree 150 still remain suspended as the Council of State has not yet brought in a decision upon the questions raised in the suits instituted by the various companies against the law and decree, and at the moment of this writing it appears unlikely that such a decision will be reached by that body.

* President and Editor, South American Oil Reports, Inc.

Effect of Legislative Situation on Company Operations

As a result of this situation and the Supreme Court decision, several companies have either cut down their staffs or have withdrawn their forces from the country altogether. Lobitos Oilfields withdrew in 1928, after the passage of Law 84. South American Gulf Oil Co. has stopped field operations in Colombia, leaving only watchmen on the properties it has under lease.

The only company operating and producing in Colombia at present, obtained its concession over 25 years ago and has a direct contract with the Colombian Government for the development of this concession. Not a barrel of petroleum has been produced and exported from Colombia under the petroleum laws which have been passed by that country since 1915. This is due partly to the fact that, despite the prospecting that has taken place during these last 15 years, no commercial fields of importance have been developed outside of the DeMares Concession, and partly to the paralysis of operation by harassing legislation.

The conviction is growing upon American oil companies that possibly the great oil riches of Colombia are more or less mythical and that, after all, but a small portion of that country will ultimately produce oil in commercial quantities. Whether Colombia will permit the development of its resources I cannot predict, but this may be stated categorically: Either Colombia will pass a reasonable petroleum law which will permit substantial oil companies to enter the country and test its resources or the petroleum will be left in the ground.

Subsoil Rights

It is to be noted that in Colombia, in contrast to Venezuela, title to the soil acquired prior to Oct. 28, 1873, carried the rights to the subsoil, and consequently to any petroleum found therein. It is to be noted also that the Spanish Ordinance of Mines which existed in Peru, Mexico and Cuba, never applied to Colombia. This history of the right to the subsoil until 1873 is clear. After 1873, the Colombian Government reserved to itself, among other substances, petroleum, when granting title to public lands. The tendency of modern legislation in Colombia has been to confirm the owner of the soil when he acquired title prior to 1873, in his rights to the subsoil, but at the same time to levy upon his property special taxes which may amount to taking that right away. The amount of the special tax has been nearly as great as the royalty imposed upon production from public lands. Its constitutionality has never been tested in the Colombian Courts.[1] Such legislation adversely

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[1] See *O'Shaugnessy's South American Oil Reports*, September, 1929, for a history of this legislation.

affects the title of every landholder in Colombia, be he native or foreigner. It is also to be noted that the Barco Concession has not been returned to the South American Gulf Oil Co., and litigation regarding this Concession is still in progress in the Colombian courts.

The operations of the companies in Colombia during 1929 may be summarized as follows:

South American Gulf Oil Co.

On the Colombia Syndicate property, the Ordoñez well No. 2 reached a depth of 5953 ft., with only slight showings of oil and gas. The well was drilled mainly in mottled clays. On the Rosario Diaz leases, Monas No. 1-A was completed to a depth of 2101 ft. and produced a negligible amount of oil. Monas No. 4 was completed at 5434 ft. and abandoned. Monas No. 6, which was drilled to a depth of 2405 ft., is now pumping on the beam; this well is producing approximately 50 bbls. per day. Monas No. 7 was drilled to 3080 ft. and apparently is a dry hole. The operations on the Rosario Diaz property are on a faulted anticline on which there are large seepages.

Standard Oil Co. of California

The Standard Oil Co. of California continued its operations on the coast. Galapa No. 2 commenced drilling and reached a depth of 2540 ft. Repelon No. 2 reached a depth of 3129 ft.; this well is testing a gas showing preparatory to abandonment. Galapa No. 1 and Repelon No. 1 are small gas wells and were drilled in 1928.

The gas from these wells was used as fuel for the No. 2 wells. Repelon No. 1 makes 500,000 cu. ft. of gas daily and Galapa No. 1 a smaller amount.

Tropical Oil Co.

A. M. McQueen writes as follows:

During 1929, this company produced 20,384,548 bbls. of crude oil. Approximately 323,036 bbls. of this production was petroleum condensate. The daily average delivery of crude for pipe line runs to the Coast was 51,118 barrels.

The total volume of crude run at the Barranca-Bermeja refinery during the first 10 months of the year was 1,442,528 bbls., with refined products as follows: Gasoline, 287,821 bbls.; kerosene, 55,172 bbls.; gas oil, 18,300 bbls.; lubricating oil, 5,911 bbls.; fuel oil, 1,066,189 bbls. The total number of producing wells completed during the year was 122, with an average initial production of 768 barrels.

The most interesting development on the Concession during the year was the successful completion of No. 2 well on the Mugrosa structure, about 19 km. south of the south end of the Infantas anticline. This well was completed with an initial production of 1300 bbls. per day of 41.4° gravity oil, at a depth of 2249 feet.

Andian Pipe Line Co.

The Andian Pipe Line Co., as will be seen from Mr. McQueen's letter, operated throughout the year at about 1100 bbls. over the rated capacity. At the close of the year this company sold to the Colombian Government its dock rights and dock at Cartagena.

The only other companies that are active in Colombia are the Texas Petroleum Co. and the Sinclair Exploration Co., both of which have acquired options on properties in Colombia but will not start operations until more favorable legislation is enacted.

Acknowledgments

The writer is indebted to the following individuals and companies for information: W. B. Heroy, Sinclair Exploration Co., R. C. Stoner, Richmond Petroleum Co.; James Terry Duce, Texas Petroleum Co.; Samuel Haskell, Texas Petroleum Co.; A. M. McQueen, Tropical Oil Co.; W. T. Wallace, South American Gulf Oil Co.

Petroleum Production in Argentina

By José M. Sobral,* Buenos Aires, Argentina

(New York Meeting, February, 1930)

Approximate figures for petroleum production in Argentina for 1929 show an increase of only about 300,000 bbl. over production for 1928. This increase is due to greater yield in the Plaza Huincul and in the Salta regions. Table 1 shows the distribution of production in the various fields of the whole country, using estimates for the later months of the year.

Table 1.—*Argentine Oil Production in* 1929

	Number of Wells in Production	Production, Bbl.	Total by District, Bbl.
Comodoro Rivadavia			
Fiscal exploitation	808	5,082,320	
Private companies	400	3,082,100	8,164,420
Plaza Huincul (Neuguen)			
Fiscal exploitation	65	389,980	
Private companies	40	629,000	1,018,980
Salta Region			
Fiscal exploitation	5	9,435	
Private companies	14	188,700	198,135
Mendoza (Sosneado)			
		157	157
Total for 1929 (for the whole country)			9,381,692
Total for 1928 (for the whole country)			9,070,242

The outlook for production remains about the same as in 1928. It is believed that in northern Argentina there are regions that contain oil, but they are yet unexplored. Notable traces of oil at depths between 1280 and 1390 m. have appeared in a 1500-m. boring in Comodoro Rivadavia, but their importance is unknown.

* Director, Dirección General de Minas Geologia e Hidrologia.

Petroleum Development in Canada during 1929

By T. G. Madgwick* and William Calder,* Ottawa, Ont.

(New York Meeting, February, 1930)

Production of petroleum increased again during 1929, thus maintaining the steady growth inaugurated by the bringing in of Royalite No. 4 in Turner Valley, Alberta, towards the end of 1924, prior to which a decline over a number of years had been experienced. The growth has been confined to the Province of Alberta, the older production in New Brunswick and Ontario showing declines, although in the latter case considerable activity in the search for new gas structures was maintained and during the last six months two wells were brought in, one at Howard in the Trenton at a depth of 1250 ft., giving 5,500,000 cu. ft., and the other at Tilbury in the Guelph or Salina at 750 ft. giving 9,000,000 cubic feet.

As has been the case during the past five years, interest in the search for structure and in the following up and development of areas already recognized has centered in Alberta and adjacent portions of Saskatchewan. This was due in the first instance to the striking of wet gas in the Palaeozoic limestone (Madison) of Turner Valley, some 30 miles south of Calgary, in Royalite No. 4 in October, 1924. The bringing in of other wells of similar importance late in 1928 and in the spring of 1929 which extended the productive area 3 miles southwards led to greatly enhanced drilling activity throughout the structure and adjacent areas and in other parts of Alberta. As a result good strikes of heavy crude oil have been recorded during the year at Ribstone, Oyen, Skiff and Coutts, in each case at moderate depths and in sufficient quanitity to justify prolonged testing. The prospects of a satisfactory production of this grade of oil are very encouraging.

Actual oil production in the west is still confined to the Province of Alberta and for all grades of oil totaled 997,359 bbl., which compared with previous years shows a gratifying increase. To this increase the naphtha obtained from the wet gas of Turner Valley has proved the principal contributant, heavy crude also showing an improvement, while the light crude, the product of the Cretaceo-Jurassic sands overlying the Paleozoic of Turner Valley, remains unchanged. This is largely owing to operators casing off these sands in their endeavor to reach the limestone, but there is evidence that in future more attention will be paid to

* Petroleum Engineer, Department of the Interior, Canada.

this source of production. The relative importance of these different grades of oil in Alberta is shown in Table 1.

Table 1.—*Production of Petroleum by Grades, Alberta,* 1925–1929

Year	Naphtha, Bbl.	Light Crude, Bbl.	Heavy Crude, Bbl.	Total, Bbl.
1925	165,717	2,926	Nil	168,643
1926	211,008	2,609	5,981	219,598
1927	290,270	38,808	3,055	332,133
1928	410,623	70,734	8,174	489,531
1929	908,936	73,060	15,353	997,359

Alberta production by fields for 1929 is as follows, figures subject to a possible slight correction when complete returns for December are obtained: Naphtha, all from limestone in Turner Valley with exception of that from Merland well brought in towards end of year in Fernie (Jurassic), 908,936 bbl.; light crude, from Turner Valley, 72,171 bbl.; light crude, from Coutts field; a new structure on International border, 889 bbl.; heavy crude from Wainwright, 11,001 bbl.; heavy crude from Ribstone, 2,930 bbl.; heavy crude from Skiff, 1,432 bbl.; total 997,359 barrels.

The naphtha production is accompanied by a large volume of gas, for the bulk of which no market has yet been found. Joint investigation by Dominion and Provincial authorities has been carried out during the past year with a view to avoiding the waste of this gas which has been on a large scale. The market for gas grows steadily and Turner Valley gas, which has to be scrubbed before use, has enabled the older gas fields of Bow Island and Foremost to be conserved but the load is subject to great seasonal fluctuations. The total consumption of gas from all Alberta fields for the nine months ending Sept. 30 was 15,145,576,000 cu. ft. An important strike of gas was made at Kinsella to the east of the Viking field, which supplies the City of Edmonton, and to which it may be egarded as a reserve for future use.

Table 2 shows the production of oil for the whole of Canada for the past five years, the figures for New Brunswick and Ontario being those of the Dominion Bureau of Statistics.

Table 2.—*Production by Provinces,* 1925–1929

Year	New Brunswick, Bbl.	Ontario, Bbl.	Alberta, Bbl.	Total, Bbl.
1925	5,376	143,134	168,643	317,153
1926	10,544	137,850	219,598	367,992
1927	18,244	139,600	332,133	489,977
1928	8,043	134,094	489,531	631,668
1929	7,800	125,000	997,359	1,130,159

Petroleum Developments in Bolivia in 1929

By Gilbert P. Moore,* New York, N. Y.

(New York Meeting, February, 1930)

Bolivia still remains among the oil countries that have proved oil acreage but no production which is being marketed. No steps have been taken during the past year to provide facilities for transport of Bolivian oil to market nor are any known to be contemplated for 1930. The only active operator to date is the Standard Oil Co. of Bolivia, subsidiary of the Standard Oil Co. of New Jersey. The potential production from completed wells is practically unchanged from the 1928 figure of 6000 bbl. daily.

As far as is known, there has been only one completion during the year 1929. This is the Machareti well, which is about 50 km. north of Villa Montes along the road to Charagua. The well is reported at about 250 bbl. daily initial production. The gravity of the oil is not known but is presumed to be about 40° Bé., the average for the region.

The Standard Oil Co. of Bolivia has five strings working on various parts of its concession. No new locations have been made definitely.

Company Activities

There was no change in the situation of American holdings in Bolivia during 1929. The oil rights of an English company, acquired under a special colonization contract with the Bolivian Government, are being negotiated in New York and may mean the entrance of another of the large American oil companies in Bolivia.

The Sucre Syndicate sold its holdings to the Standard Oil Co. of Bolivia during the past year.

A local company called the "Aguila Doble" was formed during 1929 to drill a well or wells near the town of Cochabamba on structures mapped by a local geologist. It is reported that the Government is buying about one-fourth of the capital stock of this company for 500,000 Bolivianos (about $180,000). The company has not yet raised sufficient funds to buy drilling equipment so that no operations have been started.

According to the statements published in La Paz, this company has acreage on seven anticlinal structures near Cochabamba. This area lies about 8500 ft. above sea level on the eastern flank of the Andes Moun-

* Consulting Geologist.

tains. The surface rocks are chiefly black fissile shales and indurated sandstones of Devonian age.

The only oil indications in this area are some veins of asphaltic material at a locality called Uchpa-Uchpa. They occur in combination with limestone and indurated shale.

Petroleum Legislation

The proposed new petroleum law, reported on at the last February meeting of the Institute, was presented to Congress during the past year and was referred to the Committee on Mining and Petroleum of the House of Deputies. An adverse report was presented but the Committee recommended certain changes in the existing law. These were in the form of lower taxes, lower guarantees, longer exploration periods, reduction of royalty from 11 to 8 per cent., etc. In May, 1929, a decree by the President suspended all deposits of guarantee on oil concessions. This is operative until approved or suspended by legislative action. This was done to aid the formation of the local company for drilling operations near Cochabamba.

An extraordinary session of the Legislature is being called in January or February of 1930 and the petroleum law may be considered.

Transport to Oil Fields

New developments in transport which will affect the oil regions of Bolivia are the resumption of negotiations with Argentine for extension of the railroad line from Yacuiba to Santa Cruz, completion in 1930 of the railway from Cochabamba to Aiquile, and the proposed canalization of the Bermejo River in northern Argentine.

Bolivian Petroleum Imports

No figures are at hand for the imports of petroleum and its products into Bolivia during 1929, but it is assumed that they have remained at about the 1928 level of $1,300,000. The tin-mining industry has been very slow this year and will have had its effect on the fuel oil and gasoline situation. The total number of automobiles registered in Bolivia is given as 2335 by the Bureau of Foreign and Domestic Commerce.

Gasoline retails at about 61c. U. S. gold per gal. and fuel oil at $8 per barrel.

According to published reports there has been a great increase in the number of petitions for concessions on oil lands in Bolivia, due to activity of local operators. It was also stated that the Standard Oil Co. of Bolivia had completed to date 21 wells.

None of Bolivia's potential production will reach any market during 1930.

Chapter XV. Petroleum Refining

Developments in Refinery Technology during 1929

By A. D. David,* New York, N. Y.

New York Meeting, February, 1930)

The object of this paper is to reduce to the simplest possible discussion the recent developments in refinery technology without resorting to detailed technical descriptions of the various items.

During the year 1929, the most noteworthy tendencies have been towards the installation of more flexible plants, more unified operations, more balanced performance and greater fuel economy. In no other year in the history of petroleum refining has the industry witnessed to as great a degree the crystallization of so many developments in almost every phase of the art. Economic pressure has been the controlling factor, supplemented however by a market demand for more volatile anti-knock gasoline and higher quality of lubricating oils, resulting from the extended use of high-compression motors.

Catalytic Hydrogenation

Possibly the outstanding achievement during the year has been the beginning of construction of plants by the Standard Oil Co. of New Jersey for the catalytic hydrogenation of the so-called heavier and inferior petroleum oils to produce therefrom not only high yields of anti-knock gasoline, but also lubricating oils equal in quality to the best grades obtainable. It is reported that the plants will operate at a pressure of 4000 lb. or higher and temperatures in excess of 900° F. will be used. The hydrogen required for the conversion will be produced from refinery gases. This type of processing will doubtless be an important factor in balancing future operations; in other words, it can be used to eliminate present waste products and permit production of high-grade products from low-grade crude.

Improvements in Lubricating Oils

Another important development during the past year has been the extended use of vacuum stills, making possible the production of lubricating oils from what was formerly classed as "fuel-oil crude," or crude from

* The M. W. Kellogg Co.

which only fuel residuum could be made. Better separation of the various fractions or lubricating oil distillates now makes it possible to produce pressable wax distillate free from nonviscous gas oil simultaneously with centrifugable cylinder stock and high-melting-point asphalt.

It has been reported that considerable progress has been made in continuous treatment of lubricating oils principally concerned with the separation of acid sludge by centrifuging.

In filtration of the lubricating oils to acceptable colors, the contact filtering operation is being more extensively employed and the use of continuous earth burners, such as the Wedge and Herreschoff types, has increased the efficiency and reduced the cost of clay recovery.

Much progress has been made toward the complete dewaxing of paraffin-base oils. Methods have been developed by which the lubricating stocks from the distillation and treating units are dewaxed by the centrifuge or filter aid processes. Temperatures as low as minus 45° F. are used.

The Gover process of dewaxing by use of selective solvents has been further developed and now is said to be in successful commercial operation.

Cracking Operations

Another remarkable advance of the past few months has been the rapid commercialization of vapor-phase cracking. This has been given attention primarily because of the increased demand for anit-knock gasoline. Operating cycles have been lengthened, resulting in greater economy of operation, which, together with a material reduction in amount of gas produced, makes this type of operation more practical.

Liquid-phase cracking units are now being built which are capable of producing gas, gasoline and coke only, thus eliminating the production of fuel oil which, on account of overproduction, demands a very low price. The coke formed is, in many cases, being pulverized and used for fuel in the same unit.

Where it is essential to produce fuel oil, much work has been done on the elimination of coke, resulting from cracking, with the result that some outstanding units produce little, if any, coke.

Reduction of Gas Losses

Attention is now being directed toward the reduction of gas losses from refinery operation. Absorption and stabilization plants have been erected in conjunction with topping and pressure units to recover the gasoline contained in the residual gases, in addition to eliminating the dissolved gases in the gasoline produced. By means of such installations, storage losses and losses due to handling in tank cars and station tankage have been reduced. Some of these units have been installed in conjunction with cracking equipment, utilizing waste heat from cracking opera-

tions to reboil the gasoline from the base of the stabilizer tower. The recovery of gasoline from pressure still gases averages from 3 to 5 gal. per 1000 cu. ft. of vapor, which in many cases represents as much as 2 per cent. of the original crude.

Vapor-phase treatment of cracked distillates has been incresased in an attempt to reduce acid treating, thereby preserving anti-knock value. Bubble towers have been added to this type of equipment for the purpose of fractionating out all of the polymers, thus producing a more stable gasoline.

A definite trend toward the use of crude topping and rerunning equipment for light distillate in combination with apparatus for cracking and lubricating oil distillation is noticeable. The prevailing prejudice against the combination of these so-called independent operations is giving way, because there are now in operation installations of this character which are functioning most efficiently.

Improved Apparatus

The use of shell stills is passing. Replacements are almost invariably of the tube still type. There have been many recent improvements in tube stills along the lines of increased fuel efficiency and decreased installation costs, which have been brought about largely by the increase of radiant-heat transfer surface, improvement in the convection bank design, improvement in burner design and the addition of air preheaters for recovering heat from the flue gases.

One outstanding example of this is the DeFlorez furnace, in which the total heating surface in the furnace is of the radiant type and the convection bank is replaced by a conventional type of air preheater. The design of this furnace is unique, in that it consists of a cylindrical firebox lined with radiant vertical tubes with the air preheater and stack located on the top of the unit. The burner is at the bottom of the shell, and the unit is fired up through the center. It has been successfully used in conjunction with vapor and liquid-phase cracking, topping and vacuum distillations. In general, it is usual to obtain an over-all fuel efficiency of from 70 to 75 per cent. with these modern tube still installations, as compared with the old shell still operating, showing a fuel efficiency of from 30 to 40 per cent.

The use of indirect heating methods employing such heating mediums as mercury and diphenyl have been closely studied and a few commercial installations have been made. These processes both operate under vacuum and the advantage claimed for them is that by the use of indirect heating more accurate and uniform control of temperature conditions can be obtained.

There have been many developments in the improvements of auxiliary apparatus such as pumps and control equipment. The advance in design

of hot-oil centrifugal pumps has permitted handling large quantities of hot oil at high pressures and increased efficiencies. The use of high-speed efficient turbines has materially reduced the cost of operating these centrifugal pumps. The adaptation of efficient reciprocating steam engines to driving high-speed reciprocating pumps has also been an important factor in reducing the cost of pumping hot oil.

The field of automatic control has received a most intensive study, with the result that automatic controllers are now available for controlling pressure, vacuum, temperature, rate of flow, levels and combustion. This has resulted in important savings in labor and fuel costs, and because of the uniformity of operation resulting from their use, maximum yields of specification products are permitted.

As a result of these improvements in methods of handling and control, single units are now being built for handling as much as 15,000 bbl. per day. This increased volume per unit, of course, materially reduces the unit operating cost and thereby increases the margin of profit.

Chapter XVI. Petroleum Engineering Education

By H. C. George,* Norman, Okla.

Introduction

As the basis for a round table discussion of Petroleum Engineering Education for the February, 1930, meeting of the Petroleum Division, A. I. M. E., the following questions were sent to about 60 of the leading engineers and educators in the petroleum industry:

1. Should there be any changes in the curricula of our courses in petroleum engineering to meet the changing demands of the Industry? If so, what changes?[1]

2. Should courses in petroleum engineering be offered through university extension?

3. Should the universities offer correspondence courses in petroleum engineering?

4. What should be the character of the graduate work offered in petroleum production engineering?

5. Should summer work in the oil fields, on pipe lines, or in oil refineries be required of undergraduates? If so, how much and of what character?

The following men replied to the questions:

G. B. Corless, Humble Oil & Refining Co., Houston, Texas.
J. R. McWilliams, Skelly Oil Co., Tulsa, Okla.
W. W. Scott, Humble Oil & Refining Co., Houston, Texas.
H. H. Power, Gypsy Oil Co., Tulsa, Okla.
L. G. E. Bignell, *Oil & Gas Journal*, Tulsa, Okla.
E. L. Estabrook, Pan American Petroleum & Transport Co., New York, N. Y.
F. P. Donohue, Pan American Petroleum & Transport Co., New York, N. Y.
C. O. Rison, Indian Territory Illuminating Oil Co., Bartlesville, Okla.
L. B. Holland, Phillips Petroleum Co., Bartlesville, Okla.
H. J. Kemler, Shell Petroleum Corpn., St. Louis, Mo.
C. A. Bonine, Pennsylvania State College, State College, Pa.
J. O. Lewis, Dunn & Lewis, Tulsa, Okla.
A. G. Heggem, Tulsa, Okla.
J. M. Lovejoy, Petroleum Bond & Share Corpn., New York, N. Y.
B. B. Boatright, Colorado School of Mines, Golden, Colo.
A. C. Ruble, Union Oil Co. of California, Los Angeles, Calif.
J. B. Umpleby, Goldelline Oil Corpn., Oklahoma City, Okla.
R. S. Knappen, Gypsy Oil Co., Tulsa, Okla.
K. C. Heald, Gulf Companies, Pittsburgh, Pa.
K. C. Sclater, Exchange National Bank Bldg., Tulsa, Okla.
F. G. Tickell, Stanford University, Stanford University, Calif.

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* Director, School of Petroleum Engineering, University of Oklahoma.

[1] See page 901, Petroleum Development and Technology in 1926, A. I. M. E.

H. W. Camp, Empire Companies, Tulsa, Okla.
Ben E. Lindsly, U. S. Bureau of Mines, Bartlesville, Okla.
C. E. Beecher, Empire Companies, Bartlesville, Okla.
Warren A. Sinsheimer, Henry L. Doherty & Co., New York, N. Y.
Lester C. Uren, University of California, Berkeley, Calif.
Harold Decker, Tidal Oil Co., Tulsa, Okla.
George L. Nye, Tidal Oil Co., Maud, Okla.
G. R. Henson, Shell Petroleum Corpn., St. Louis, Mo.
Ernest R. Lilley, New York University, New York, N. Y.
Arthur Maddox, Carter Oil Co., Seminole, Okla.

The written discussion developed by the questionnaire was presented in mimeographed form at the February Meeting and a limited number of copies are available to educational institutions at Institute headquarters. This discussion may be briefly summarized as follows:

Question 1: The leading idea advanced was that more attention should be given to the function of natural gas in the production of oil.

Question 2: Most of the replies favored extension courses.

Question 3: Most of the replies were opposed to correspondence courses.

Question 4: Most of the replies were in favor of confining graduate work to research on specific problems.

Question 5: Opinion was divided.

DISCUSSION*

H. C. George.—I had a purpose in sending out the five questions. Much of my time is taken in answering letters pertaining to correspondence on extension courses in petroleum engineering; another matter that claims attention is the demands that the University of Oklahoma, Extension Department, is receiving for courses in petroleum engineering. The tenor of the replies conformed with my personal opinion on the demand. My experience showed that nine out of ten of the boys who wanted correspondence courses in petroleum engineering had had no basic science, and when they were informed that an essential knowledge of mathematics and chemistry and physics and geology was required, they lost interest.

1. Should There Be Any Changes in the Curricula of Our Courses in Petroleum Engineering to Meet the Changing Demands of the Industry?

H. T. Mann,† Cambridge, Mass.—In looking over the catalogues of petroleum engineering, I found the same trouble or the same lack that was so prevalent a number of years ago in mining and metallurgical curricula; that is, the various courses emphasize practice at the expense of business.

We are not trying to prepare men to be drillers or to occupy similar positions all their lives. They are going ahead to positions where they will have to handle men and look after business details, I believe they will be much stronger if they are given more business training at the expense of some of the engineering practice.

Other than the above I would not suggest many changes in the curricula.

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* There was no oral discussion of question 4.

† Associate Professor of Petroleum Engineering, Massachusetts Institute of Technology.

E. R. Lilley,* New York, N. Y.—To what group of men would you give these business courses?

H. T. Mann.—All of them.

E. R. Lilley.—In my experience the so-called business group of teachers, the economics teachers, present little of value to the engineer.

H. T. Mann.—I will agree with you, but it is possible to work in a good deal of business in a course in petroleum practice. Take an illustration from the mining industry. I believe the general practice would be to use Peele's "Handbook of Mining" for a text in the fourth year mining practice. That gives a man nearly all practical work. Why not use texts such as Hoover's "Principles of Mining," or the book by Findley? They are full of good practice and at the same time they are handled from the business standpoint.

H. H. Power,† Tulsa, Okla.—I agree with the statement just made. We find that one of the hardest things to accomplish in an operating company is the proper understanding on the part of the engineer of the economics of the business, and especially matters pertaining to engineering costs. It seems to me that at least some attempt should be made to assist an engineer in acquiring a general view of business fundamentals. His skill as a technical engineer should not distract his attention unduly from the broad aspects of business practice.

I. I. Gardescu,‡ Pittsburgh, Pa.—In most cases undergraduate students are not sufficiently prepared to undertake research work in petroleum engineering. I have seen, in a technical institution of high standing, a student working on a problem of recovery, who had not the slightest idea of what an oil sand looked like. I have seen, in a school of engineering, students working on the theory of flow of oil, who never had any physics and chemistry beyond their freshman year. There is a great demand for sound research work in the oil industry. I suggest that students be trained in the technique of research in petroleum engineering in a manner similar to the training given to the student in chemistry. Original research should be carried out only by students who are equipped for the work; preferably by those who have had some practical experience with petroleum engineering problems.

2. Should Courses in Petroleum Engineering Be Offered Through University Extension?

E. R. Lilley.—Before we go into this question will someone define for me what the general understanding of the term "university extension" is? Does it mean evening courses within the university or does it mean courses given away from the university in adjacent towns?

H. C. George.—As I understood it and as we use it, it means both.

E. R. Lilley.—There is a difference as far as I am concerned.

R. H. Johnson,§ Pittsburgh, Pa.—I would say that the answer lies in the demand. If there is a demand that justifies the effort, we should certainly do it. The grade of work to be done also is a function of the type of demand. If trained men want something supplementary, give them something of that sort. If the demand comes from men that can take very little, let the material be adapted. I do not think any harm will result, and some good may, where there is enough demand, but I do think

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it is questionable to try to force university extension where demand is inadequate and to devote a good deal on effort for a few students of inadequate preparation.

H. T. Mann.—Too often, extension courses are given at the expense of the staff of the university. Men leave the university to give a course in extension work at some other place; they are usually fairly busy and time has to be given which otherwise would be devoted to the university work. Often, also, as has been said, the men applying for extension courses are not prepared for the work they want.

T. T. Read,* New York, N. Y.—Very often the demand does not exist unless facilities are created for supplying the thing which is to be consumed. I think it would generally be the experience that if a school started extension work it would take a little time to build up the market, just as it takes any manufacturer time to build up his market. People do not know that the service is available; also, perhaps they are not "sold on the idea" that it would be worth while to use it.

As Dr. Lilley pointed out, there is a difference between extension work and what we call "home study" work. Extension, with us at Columbia University means courses given outside of the regular school hours, in the evening or late afternoon, for which the students come to the school, whereas home study does not involve attendance at any classes. Those have entirely different set-ups with us.

The home study people pay the regular university people for doing the necessary work on the home study courses, and the University cooperates to the extent of relieving the teacher from duty so that he can devote time to preparing material for home study work. But the home study does pay the teacher; it is not simply another burden loaded on a patient teacher's back. It has worked rather successfully with us and so far our home study work has gone on a pay-as-you-go basis; it carries its own cost. We have never attempted any home study work in petroleum. I do not know whether we should. In our case it would have to be integrated with an already existing set-up.

I think that you cannot expect people to come to your door, asking you to do something for them. It may often have to work the other way; that you have to be prepared to give a useful service before a demand will develop for it.

H. T. Mann.—Even though the teachers are supposedly relieved of other duties, there are men teaching the home study courses who are carrying loads that are too heavy for them. In one course that I know of the teacher has once or twice apologized because he reached the meeting place and sat down for a few minutes to rest before the lecture started, and went to sleep.

E. R. Lilley.—The other side of the extension work is a little different from the side that Professor Mann brings out: a large number of the men around Columbia and New York universities are most anxious to teach extension work because it means extra pay.

To me the word extension means courses given primarily outside of the university buildings. In New York that might mean perhaps courses given in Bayonne or Paterson or Westchester County. Courses given at the university in the evening we do not always term extension unless they are courses that do not lead to degrees and are not given by degree-granting schools. The courses that may be given in adjacent towns are good publicity for any school, regardless of whether the value is there or not.

As far as the petroleum course is concerned, we have near us probably the largest single refining center in the world in Bayonne, yet I have not seen any good reason for making the suggestion that the university give an extension course there. The

* Vinton Professor of Mining Engineering, Columbia University.

demand is most variable; it is very high at one moment but after about three weeks of the fundamentals, given in order to make it possible to talk intelligently about the more advanced material, the students drop out.

On the other hand, when we make the student come to us for an extension course in the evening, somehow or other we manage to keep them coming year after year, without an undue amount of advertising, and it seems to spread around that you can get something worth while in such an extension course. Within the walls of the university the evening type of course seems to us to be very successful.

C. V. Millikan,* Tulsa, Okla.—Dr. Lilley's comment on maintaining interest is of vital importance. I happened to come in contact with one of our bosses who was taking a correspondence course, and he asked me several questions about it. I found that he was spending all his time on fundamentals. I do not want to belittle the necessity for fundamentals in order to carry on more advanced work, but in either correspondence or extension, in order to maintain interest why not start immediately with problems that will create the fundamental knowledge by the working of simple practical problems which he meets every day?

A student is too apt to fail to see the application of the fundamentals—the simple chemistry, physics, mathematics; the basic courses—to his work, and as a result soon becomes uninterested.

3. Should the Universities Offer Correspondence Courses in Petroleum Engineering?

T. T. Read.—Correspondence courses have been under something of a cloud because the earliest correspondence courses were intended for uneducated men. They were intended to teach the simplest things. The universities that carry on correspondence courses in advanced subjects and many of the large universities do, carry them on successfully in many instances. I see no reason why that cannot be done with petroleum engineering, nor why correspondence work should be hampered by the "roughneck" associations of its earlier days.

The course which our own Home Study Department at Columbia offers in gas engineering is exceedingly successful. One of the professors is paid for doing the work necessary for getting the study material properly prepared and the papers corrected. With the cooperation of the American Gas Association, a successful home study course has been developed.

H. C. George.—The thing that I have noticed in connection with this demand for an extension course in petroleum engineering is that the vast majority of those who ask for it are deficient in basic science, and the moment you mention that they should have the basic sciences they are no longer interested. They probably represent nine out of ten. The tenth is probably a man with a degree in some branch of engineering and he asks for a petroleum engineering course. As I have analyzed it, a man with a basic engineering degree is as well qualified as the teacher to go into the literature on the subject, and secure the information; so I personally have felt that if you could say that the basic science course was petroleum engineering, call it that, you could probably do much good.

T. T. Read.—Is not interpretation the thing you need? It is true that these people can read literature, but the question in their minds often is, what does it all mean?

H. C. George.—There is so much interpretation. What a man is perhaps after is not interpretation that he can secure by description and narration on the part of the

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* Production Engineer, Amerada Petroleum Corpn.

professor, but something he has to see and handle himself, and a man can only get that by experience.

E. R. Lilley.—I feel that correspondence work in advanced courses would be undoubtedly the most satisfactory to me personally, but I know it would not be satisfactory to the administration of any university that was not heavily endowed. Dr. Read mentioned the cooperation of the American Gas Assn. in the the gas engineering course. If the American Petroleum Institute would do likewise, it might go, but as far as the demand is concerned, the number who want particular phases would be rather limited, and universities, unless they are endowed, cannot afford to take a chance.

I am more interested in the question of the "under dog" who wants to rise. The situation that comes up is this: I have a steady stream of letters from men somewhere in the middle of Kansas or in the middle of Wyoming, or in the Maracaibo Basin, or up in Alberta, who want to know where they can get information about petroleum engineering or petroleum marketing problems. I write them that if they have four years to spend, they should go to the University of Oklahoma, and if they are going to be in New York to come and see me and I shall be glad to see what I can do for them here. But I know they are not going to be able to take four years off, and I know that their work is not going to be of such character that they can come to New York.

What am I going to tell such men? My university is against correspondence school work. I do not know of any university giving correspondence school work. I hesitate to recommend certain of the correspondence schools proper that have attempted to take up that work. Is there anything that can be done for the fellow who is trying to pull himself up a little under these circumstances?

5. Should Summer Work in the Oil Fields, on Pipe Lines, or in Oil Refineries Be Required of Undergraduates? If So, How Much and of What Character?

R. H. Johnson.—I have been trying to do this for several years, because I know it is desirable, but there have been some difficulties. We do definitely require a summer in camp and we exert every pressure we can to get a summer afterwards in practical experience, and one of the most useful means is to let the students understand that if they have had this extra esxperience they can be placed to better advantage. But when it comes to making it an absolute requirement we run into the difficulty that so many of our boys cannot afford it. Some of the students are even making money during the winter term, and many have to put money first in choosing work for the summer term. The distance that it is necessary to go to get work in many cases is a factor.

H. T. Mann.—While we agree with everyone that field work is desirable, and the more the better, still I have a feeling that a school should not require any work outside of its own instruction, during the course. If they wish to take the men to the oil fields, or in mining courses take them to the mines, it is a good thing, but as for requiring the men to go out into the fields and work, I do not think it should be done.

There is one point to consider, and that is that the men are coming in contact with bad practice as well as good, and so often an instructor will spend a large amount of valuable time trying to straighten a man out on some of the things he has learned in the fields which he would have been better off had he not come in contact with. After men have developed judgment so that they can tell the good from the bad, the practical experience is worth a good deal more.

By the time the young man is through with his course at school he has had the fundamentals and he should be prepared to reason out things for himself, and in that way pick out the good from the bad, while as a student he has not yet sufficient fundamentals to make it possible for him to do the selecting.

H. H. Hill,* New York, N. Y.—I think it depends entirely on the student. A husky fellow can go out and dig ditches or work around tank farms, but many of our best engineers in the past have been very strong physically and some of the men now being trained as engineers are not physically able to do hard manual labor. If those men are required to go out and work with the roughnecks around drilling wells, we will lose them from the engineering profession.

All of the petroleum engineering students should get some field experience if possible, but certain types of men would be better placed in the engineering departments than out in the field, doing simple work like setting meters, reading meters and calculating charts. Experience of that kind will be more valuable to them later than shoveling sand around tanks or digging ditches, because they will not have to do that kind of work when they get out of college, and although it may give them the field man's viewpoint, in many cases they can do better engineering work if they go into the field after graduation with an open mind on all practical problems.

Another point we should consider is that the average age of college graduates is going down. Many of the graduates are very young, and most of them are not fully developed physically. They really are not able to do the manual labor that is expected of them, and yet they have to go out and do their share. A boy who is going to graduate in petroleum engineering wants to show that he is as much of a man as any other fellow on the job, but if he tries to keep up with some of the husky men around drilling wells, he will probably ruin his health. The fact that these boys are being pushed so fast is a good reason why many of them should take a summer vacation forget all about study and rest up for the next year. We are beginning to need more and more who are trained in the fundamentals of engineering, rather than in the practical phases of the work.

For that reason, it would seem advisable to carefully select the men that are sent into the oil fields during summer vacations.

E. R. Lilley.—Most students are rather low in funds and it seems that there is less money in digging ditches for three months than there is in waiting on tables at a hotel.

H. C. George.—It would seem to me that the schools in this country offering petroleum engineering as a major group ought to get together and have say three of their number, one on the Pacific Coast, one in the Middle West, and one in the East, offer a summer course to take care of the group that Mr. Hill mentioned—men who are physically unable to do field work. Say, for instance, in a given summer, the institution on the Pacific Coast offering the course might make a study of gas and oil pipe lines, and the group in the Middle West might make a study of air-gas lift, and the one in the East might make a study of flooding.

If three institutions, representative of the best schools, would cooperate in that way, it would seem to me that it would add materially to the work being done by these schools, and would aid the petroleum industry.

R. H. Johnson.—The suggestion of possible cooperation between us is worth while. The demand that Dr. Lilley has spoken of for correspondence work is very scattered and there is not enough of it to justify more than one institution in the country doing it. If some one institution, possibly Columbia, in view of its great experience in correspondence work, would undertake it, I am sure I would be glad to forward the correspondence requests I get, because there is not enough of it for us to venture into it, but I think that collectively, all over the country, there is enough for one and only one institution.

* Petroleum Engineer, Standard Oil Development Co.

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